Evaluating the Effectiveness of Thematic Mapping on Virtual Globes

By

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ABSTRACT

Virtual 3D global representations of the earth (such as Google Earth) have over the past seven years become nearly as ubiquitous as traditional 2D (“flat”) maps. Because of their novelty and popularity, it is necessary for cartographers to evaluate the potential of virtual globes as a thematic mapping medium. Through a series of thematic map comparison tests and surveys, I evaluate participant performance using two map media (2D flat maps and 3D virtual globes) and two quantitative symbolization methods (choropleth and prisms), and participant preference for each variable combination. I test hypotheses regarding the effects dimensionality, interactivity, and dynamism have on participant map reading, value identification and estimation accuracy, task completion times, and preference. The results indicate that symbolization dimensionality, not map medium dimensionality, is responsible for significant differences among participant accuracy rates and completion times; in particular, symbol dimensionality increases result in significantly lower accuracy rates and significantly higher completion times. However, the results also show that participants perform best using the 2D flat map and 2D choropleth map combination and worst using the 3D virtual globes and 3D prism map combination.

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And to Cab and the sprout: boom boom.

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CHAPTER 1: INTRODUCTION

1.1 Background

The proliferation of personal computers, the Internet, and free or inexpensive mapping software, applications, and data has dramatically changed the way humans view and understand the Earth. Historically, the time, expense, and expertise necessary to create and distribute maps established a powerful one-way relationship between mapmakers and map readers. These restrictions led to the establishment of specific cultural perspectives and design frameworks that traditionally have dominated mapmaking. Today, however, anyone with access to a computer and possessing even the most basic of computer skills has the ability to create, view, and distribute high-quality maps. A popular phrase used to describe this procedural shift is the "democratization of cartography" (Morrison 1997, 17), whereby, through technological innovation, the power to create a map shifts from the hands of professional cartographers to the public. As part of this democratization of cartography, three-dimensional (3D) virtual globe (VG) representations of the Earth such as Google Earth, Microsoft Virtual Earth, and NASA World Wind have, over the past six years, become nearly as ubiquitous as traditional two-dimensional (2D), planimetric "flat" maps. Because of novelty and popularity of VGs (Google alone claims over 500 million unique downloads of Google Earth since its 2005 launch; see Hurowitz 2010), cartographers must re-examine the current design framework and determine whether thematic maps are effective when displayed in these environments (Hegarty et al. 2009).

For expediency, thematic maps are often separated into two categories: general-reference and thematic. General-reference maps emphasize the location of geographic phenomena, whereas thematic maps emphasize the distribution of geographic attributes or variables (Slocum et al.

2009, 2). Free VG applications possess the ability to display both general reference and thematic data, but their current usage gravitates heavily toward general-reference data (see Butler, 2006; Schoning et al. 2008). For both general-reference and thematic maps, cartographers have adopted guidelines for determining the appropriate graphic representation and symbolization of quantitative and qualitative data (e.g., Krygier and Wood 2005; Robinson et al. 1995). A complication in applying these rules of representation when displaying thematic data on VGs is that they were developed for traditional 2D maps and thus may not apply to VGs (Häberling et al. 2008).

1.2 Research Objectives

The purpose of this thesis is to contrast the effectiveness of representing global thematic datasets on VGs versus traditional 2D maps. This is accomplished by measuring the map-readers' abilities to work with 2D and 3D data symbolization methods displayed in each environment, thus enabling comparisons between map medium and symbolization method. By measuring map-reader performance, this study has two objectives: 1) determine if VGs are an effective medium for displaying global thematic data, and 2) establish guidelines for determining appropriate methods of thematic data representation on VGs either by adopting existing guidelines or developing new guidelines altogether.

1.3 Research Questions

To investigate the effectiveness of thematic mapping in VG environments and to meet the stated objectives, this thesis addresses four questions:

1. How well do users acquire, interpret, and retain global thematic data displayed on VGs compared to traditional 2D "flat" maps?

2. How does user performance compare when 3D symbolization (prismatic maps) and 2D symbolization (choropleth maps) are utilized?

3. What representation(s) of spatial data do map readers prefer (2D maps featuring 2D or 3D symbolization, or 3D maps featuring 2D or 3D symbolization)?

4. Do existing cartographic design guidelines apply to thematic maps displayed in the VG environment?

Map-reader performance can be measured through: 1) accurate data acquisition, and 2) accurate data memorization and recall (Slocum et al. 2009, 3, 268). In this thesis, map-reader preference is evaluated by comparing user opinions regarding each 2D and 3D map type and method of data representation. These measurement and evaluation methods are discussed in chapter three of this document.

1.4 Hypotheses

Hypothesis 1: User performance will decrease as map dimensionality, dynamism, and interactivity increase.

The cartographic literature indicates that the characteristics of the VG environment (dimensionality, dynamism, and interactivity) present a number of unavoidable perceptual obstacles that prevent viewers from effectively and efficiently viewing and remembering displayed data (e.g., Lowe 2003; Harrower and Fabrikant 2008; Roberts 2008; Hegarty et al. 2009). Within this thesis, these characteristics combined determine a map's *display complexity*.

Hypothesis 2: Users possessing superior cartographic, geographic, and graphic literacy will perform more accurately than those possessing inferior cartographic, geographic, and graphic literacy.

The experiment assesses three types of literacy, also referred to in this thesis as *map reading skills,* that support map reading tasks: geographic literacy, used here to describe the ability to comprehend, identify, and navigate to geographic locations; cartographic literacy, used here to describe the ability to comprehend, understand, and analyze the visual grammar of maps, including color and symbolization meaning; and graphic literacy, or spatial visualization ability, used here to describe the ability to comprehend, understand, and mentally manipulate spatial forms, which is particularly important in 3D environments. The expectation is that participants with such skills will perform better than those without these skills.

Hypothesis 3: Task completion times will increase as map dimensionality, dynamism, and interactivity increase.

Increases in map complexity, which in this research refer to the increases in dimensionality, dynamism, and interactivity, are expected to require longer amounts of time to complete the test tasks. This expectation stems from the fundamental environmental difference between flat maps and VGs: the entire dataset displayed on a flat map can often be viewed from one perspective and with a minimum of interactivity, whereas VG users must dedicate additional time adjusting the display perspectives in order to view the entire dataset mapped on the VG.

Hypothesis 4: User preference for a particular map will increase as map dimensionality, dynamism, and interactivity increase.

Previous research indicates users prefer complex map displays over simple map displays, regardless of the effects complexity has on performance (St. John et al. 2001; Smallman 2005; Hegarty et al. 2009). Because of this preference, an expected result of this study is that users will prefer VGs even if their performance is better using a more traditional map.

1.5 Key Issues and Definitions

Prior research suggests that VGs may be unsuited for displaying thematic data (Häberling et al. 2008; Harrower and Fabrikant 2008; Hegarty et al. 2009), but empirical studies that validate this view have not been published. Further, the ease of acquisition and widespread use of VGs may trump any "rules" made by professional cartographers regarding their usage; that is, via the "democratization of cartography," users may utilize VGs in any manner regardless of pre-supposed suitability. Creators of datasets for display in VG environments are faced with two conflicting forces (Ware 2004): the need to produce the best possible visual representation of the data for the task at hand and the need for consistent guidelines shaping all visual representations regardless of the task at hand (in general terms, broad guidelines that are applicable to every mapping scenario). Smallman and St. John (2005, 12) suggest two other key considerations necessary for good display: knowledge of the data requirements of the tasks for which the displays are used and knowledge of how the user's visual perception is likely to transform and interpret the data displayed. Without a clear set of map design principles guiding thematic data representation (or at the very least identifying inappropriate representations) in interactive, global, 3D environments, the potential for inadvertent or deliberate misuse is considerable.

VGs offer a feature unique in popular mapping: they can display mapped data two-dimensionally or three-dimensionally in dynamic, interactive 2D and 3D environments. For the purposes of this thesis, *dynamic* refers to the ability to display change, including the passage of time, the movement of objects, and the availability of multiple viewing perspectives, through user-controlled animation. *Interactive* refers to a user interface that responds to the user by changing the appearance and content of the displayed data. *2D* refers to a vertical view of a surface, *3D* to a perspective view of a three-dimensional surface displayed in two-dimensional media (such as a computer monitor), and *dimensionality* refers to either 2D or 3D. Stereoscopic 3D visualizations, which create the illusion of depth through binocular disparity, were not considered for examination. Lastly, *display complexity* refers to the degree of dimensionality, interactivity, and dynamism of a particular map display. Each of these concepts are explained or illustrated later in this text.

CHAPTER 2: LITERATURE REVIEW

2.1 Background

A survey of thematic mapping literature reveals both an abundance of research on thematic map design and use (e.g. MacEachren 1995; Slocum et al. 2009) and noticeable deficiencies in attempts to apply or analyze this research in the context of VGs (Häberling et al. 2008; Fabrikant and Lobben 2009). Two temporal obstacles to current research are the novelty of VGs and the transitory nature of computer hardware and application software. The relatively young life of VGs, only about seven years old, has provided little opportunity for long-term empirical studies. The fast pace of application innovations and upgrades and expanding hardware capabilities, which consistently introduces new technology while rendering old technology obsolete, also poses a challenge to long-term studies. Critiquing progressive technology is challenging when the totality of its capabilities and its shelf life are unknown. The evaluation of the ability of VGs to display thematic maps is an example of these challenges, as this capability was not an original function of VGs, and only after this capability surfaced were any formal evaluations attempted (Häberling et al. 2008; Harrower 2009).

Other obstacles impeding VG evaluation present themselves in particular circumstances. These circumstances include the purpose of VG use (private, professional, or academic); the setting and scale of its use (e.g., room size, number of users); cost considerations affecting selection (e.g., free, moderately priced, and expensive VGs are available), features, and performance (free versions often have limited functionality); and the potential difficulty of manipulating source code (some VGs are open source, others are proprietary). Attempts to account for each of these obstacles and how each affects VG use are beyond the scope of this thesis.

This thesis operates under the assumption that VGs will not disappear from popular use in the foreseeable future (Google Earth software updates occurred as recently as January 2012) and so looks beyond the differences among VG software and focuses instead on the difference between VGs and traditional maps. In general, the media used in this study, traditional 2D maps and VGs, occupy opposite ends of a spectrum. Traditional 2D maps are generally flat, non-interactive, and static (animated or zoomable 2D maps are an obvious exception). VGs are 3D, dynamic, and fully interactive (Table 2.1a).

		Traditional Paper Maps	**Virtual Globes (many properties dependent on hardware capabilities)**
Features	Size	Small to large; flexible, foldable	Small, fixed to display resolution
	Power consumption	None	Significant: endurance limited to power source
	Price	Inexpensive	Free to expensive
	Reliability	High	Variable
	Weight	Low	Wide range
	Mobility	High	Low (desktop computer) to high (handheld device)
Content	Resolution (spatial)	High	Low to high
	Resolution (temporal)	Limited (static)	Potentially high
	Flexibility of content	No adaptation; difficult to update	Easy
	Scale	Limited (static)	Flexible, potentially unlimited
	Level of Detail	Fixed, variable (use specific)	Flexible, low to high
	Readability	High	Low to high
	Layering	Not supported	Supported
	Animation	Generally not supported	Supported
Use and Interaction	Ease-of-use	Easy	Easy (dependent on software)
	Ease-of-learning	Easy (learned map skills required)	Easy (basic computer skills required)
	Ease-of-access	Widely available	Requires hardware
	Perspective view	Fixed	Flexible, potentially unlimited
	Annotation	Simple (with pens, post-its, etc.)	Only if supported by software
	Query, Search	Only pre-designed indices	Full support depends on software
	Integration with GPS	None	Full support depends on software
	Multi-user interaction	Easy, limited by size	Easy, unlimited through internet
	Creation of new maps	Unlimited	Limited
	Ease of map creation	Variable, depends on intended quality and mapmaking skill	Variable, software or coding skills usually required.

Table 2.1a: Comparison of traditional paper maps and virtual globes (Adapted from Paelke and Sester, 2010).

The cartographic research relevant to this thesis is grouped into four general topics: 1) critical issues facing current cartographic design research; 2) characteristics of the VG environment (dimensionality, dynamism, and interactivity); 3) the effects of these characteristics on user performance; and 4) critiques of existing and proposed VG applications. Each topic is crucial to establishing a cartographic design framework applicable to VGs. However, even if cartographers create such a standardized framework, it may not be adopted by VG users (Schoning et al. 2008; Hegarty et al. 2009). The standardization of VG technology is likely to follow the trends of popular usage, especially in the absence of empirically-grounded research (Roberts 2008; Sheppard and Cizek 2009).

2.2 Critical Issues Facing Current Cartographic Design Research

A review of the literature indicates that cartographers are well aware of the deficiencies and limitations of existing cartographic research as it pertains to VG technology (Bleisch et al. 2008; Fabrikant and Lobben 2009; Häberling et al. 2008; Hegarty et al. 2009) and that they are generally in agreement on a few critical issues. Interestingly, even though each issue was identified long before VGs came into widespread use, formal attempts to address any of these issues are scarce (Fabrikant and Lobben 2009, 139). The first issue is the need to evaluate the design and implementation of dynamic, interactive 3D displays utilized by VGs. These displays provide abundant visualization options, but researchers have not sufficiently evaluated the effects these visualization methods exert on data displayed within the VG environment. As a result, little or no guidance is available that helps users select data appropriate for VG displays (DiBiase et al. 1992, 203-204; Lobben 2008, 583).

The second issue is the need to focus on cognitive issues and usability and evaluate the effects VG displays have on users' abilities to obtain, analyze, and remember visualized information. Systematic, empirical research evaluating the effectiveness and efficiency of VGs as tools for learning and understanding remains scarce (Garlandini 2009, 196), as does research exploring the effects of the relationships between the application characteristics, the data characteristics, and user performance (Lobben 2008, 584). A key issue is *task-suitability*, identifying those tasks for which the technology (Harrower and Fabrikant 2008, 52) and the data (Fairbairn 2001, 16; Fabrikant 2005, 22; Slocum et al. 2009, 5-6) under study are mutually suited.

The third issue is to determine whether traditional cartographic design principles are applicable in VG environments or if new principles must be developed. Fabrikant (2005, 2) suggests traditional cartographic design principles may only partially apply, whereas Patterson (2001, 100) and Shepherd (2008, 200, 217) suggest they do not. Häberling and Bär (2006, 11) claim that theory and principles about 3D map design are almost non-existent and that the technical aspects of 3D map creation and visualization remain the primary focus of research (Häberling et al. 2008, 178). To fill this void, cartographers must make a concentrated effort to establish a design framework for VG environments (Shepherd 2008, 217), ensuring that further innovations in VG technology incorporate appropriate methods of geographic visualization and data representation.

This literature review addresses each of these issues as they apply to thematic mapping and to VGs. Although long-term, empirical studies involving VGs are lacking, the literature contains a numerous studies examining each VG characteristics outside the VG environment (for example, DiBiase et al. 1992; Fabrikant 2005; Harrower 2007a, 2007b; Shepherd 2008; Ware 2000).

Individually and in tandem, these characteristics have well-established effects on user performance and knowledge tasks, cognition and memory, and even on a user's ability to self-assess his or her own learning and performance (Hegarty et al. 2009). Evaluating the appearance, purpose, and impact any representation of data has on user understanding and performance is essential to assessing how well all VG users, expert and non-expert, utilize VG technology (Fairbairn 2001, 16). VGs must be thoroughly suitable to the task(s) for which they are utilized. In this thesis, these issues are addressed by focusing on the three most distinctive characteristics of VGs: their multi-dimensional, dynamic, and interactive characteristics.

2.3 Dimensionality

2.3.1 Dimensionality in the Virtual Globe Environment

The most striking difference between VGs and traditional maps is dimensionality. Traditional maps utilize 2D, "flattened" projections of a 3D surface, whereas virtual globes are distinctly 3D. An interesting characteristic of VGs, however, is how they appear to shift dimensionality depending on viewing angle and scale. In the default view, the entire globe is displayed in the frame and the surface appears to be 3D; if the viewing perspective remains vertical (looking straight down) and the scale increases such that the horizon is outside the field of view, the surface appears 2D; and if the viewing angle is tilted to display an oblique perspective, the surface once again appears 3D.

Determining when and how to use 2D or 3D at any stage of the cartographic design process is a complex decision with no universal answer; instead, as with any thematic map creation, the process depends upon the purpose of the map and the phenomena being mapped (Slocum et al.

2009, 79). Dimensionality affects displays, which can be 2D (e.g., flat maps) or 3D (e.g., virtual globes, although special technology is required to view these globes in true, stereoscopic 3D), and map perspectives (viewing angle), which can be 2D (vertical) or 3D (providing depth). Dimensionality also affects the usability of VGs; usability is a central component of successful mapping, and ideally the cartographic design framework is shaped to produce the most efficient, accurate depiction of selected data possible for user ease and accuracy. To address the role of dimensionality in the design process, Shepherd (2008, 200-201) asks three key questions that must be answered to prevent the arbitrary selection of 2D or 3D: 1) When are 3D visualization techniques appropriate? 2) Which 3D techniques are most appropriate for specific situations? and 3) When are 2D techniques more appropriate?

Dimensionality is the focus of considerable cross-discipline scientific investigation. In a review of empirical tests of 2D and 3D displays, St. John et al. (2001, 80) state that the empirical evidence for the utility of 3D views is mixed. Some studies identified 3D as superior to 2D, others identified 2D as superior to 3D, and some found equivalence or disparity between the two, depending on the tasks or measures used.

2.3.2 Dimensionality and User Performance

2D and 3D displays support different types of spatial tasks (Hegarty et al. 2009; Cockburn and McKenzie 2002; St. John et al. 2001; Shepherd 2008). 2D displays support location positioning and measurement tasks but are unsuitable for tasks that require understanding general shapes of 3D objects; conversely, 3D displays are useful for shape-understanding tasks but poorly suited for position and measurement tasks. This suggests VGs are useful media for thematic datasets if the purpose is not dependent on relative position and/or distance judgments (Smallman 2005, 8).

St. John et al. (2001, 80), Smallman and St. John (2005, 8), and Shepherd (2008, 204-209) identify several problems inherent to 3D usage that affect perspective, the data displayed, and map reader performance. First, scale is inconsistent in 3D perspective, making visual comparisons of objects difficult. Second, the perceived location and size of objects vary with every viewing angle, which makes location assignments and distance measurements difficult. Third, object widths and depths in 3D perspectives compress and expand at different rates, making an object appear larger or smaller depending on the viewing angle. Finally, 3D visualizations suffer from occlusion, where near objects obscure other objects in the background.

Hegarty et al. (2009, 173) noted that users behave as if oblivious to the problems of depth and width, assuming everything compresses and expands at identical rates. This misconception hinders the perception of relative distances and angles, and like the problems of scale, leads to errors in object comparison and measurement. Further complicating dimensionality usage is that it is not limited to the display or media, but it is also a characteristic of the thematic representation of the data. Thematic data can be visualized as 2D (flat on the map surface) or 3D (projected off the map surface) (Figure 2.3a), but the inherent problems of scale, location, depth, and occlusion adversely affect data represented by 3D symbolization and so restrict its utility in 3D environments. Jenks (1963; 1971) described the utility of representing thematic data in 3D to help map readers understand distributions and extract information, but he did not explain sufficiently how to avoid occlusion in the traditional environment.

Figure 2.3a: The Google Earth image on the left displays 2-D data (the push pin and aerial photo of the University of Kansas campus buildings) in a 2-D environment. At right, the image of the same scene also displays 3-D data (3-D buildings draped over the photo) in a 3-D environment. © 2012 Google, image © 2012 Terrametrics.

To rectify this problem, Slocum et al. (2009, 91-3) suggest manipulating the map in an interactive environment, changing the perspective such that all data are viewable in the display. Sandvik's (2008) thematic maps for VGs utilize this solution to bypass occlusion, but scale, depth, and location problems persist. (Figure 2.3b).

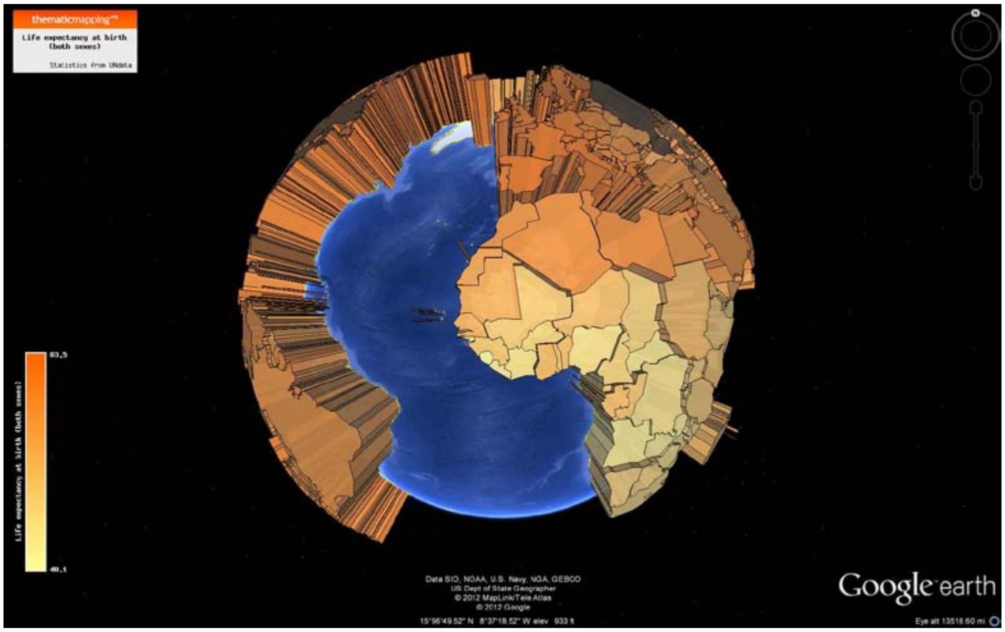

Figure 2.3b: Thematic maps created using Sandvik's Thematic Mapping Engine are viewable in Google Earth's interactive environment. The properties of the globe distort the appearance of the data and encumber scale, depth, and location assignment tasks. © 2012 Google, © 2012 Tele Atlas, © 2012 Bjorn Sandvik.

A hypothesis of this thesis is that users will perform better using displays that show the entire dataset in one view – that is, the flat, 2D projection used by traditional maps. In this static setting, dimensionality problems are usually either minimal or non-existent. As this research concerns *global* thematic datasets (which, in the VG environment cannot be displayed in one view), dimensionality is incorporated in two ways: the mapping media (2D flat maps and 3D globes), and the thematic data symbolizations (2D choroplethic polygons and 3D prismatic polygons) (Figure 2.3c).

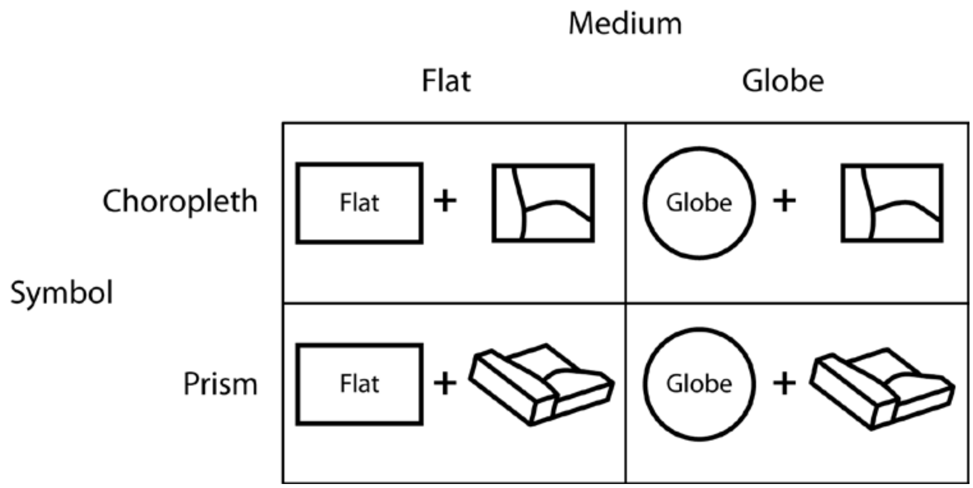

Figure 2.3c: Experiment map medium-symbolization combinations. Every participant will view each map combination.

The working assumption is that user performance will be markedly different when viewing each type of symbolization in each type of map medium, as will user preference for each type of medium/symbol combination. This assumption is built into two hypotheses of this thesis, that quality of user performance will decrease as symbolization or map medium dimensionality increases, whereas user preference for a symbolization method or map medium will increase as dimensionality increases.

2.4 Interactivity and Dynamism

The literature shows the key difference between interactive and passive maps is the degree of control the user has over the map medium and content, while the difference between static and dynamic maps is *change,* whether it be attribute, temporal, or spatial. Interactivity and dynamism are functionally inseparable characteristics of VGs. Other map media, such as animated maps, can be dynamic and not interactive, but VGs are necessarily both. Various levels of interactivity and dynamism are known to affect users in many ways and, as with dimensionality, are the focus of considerable research (for example, Harrower and Fabrikant 2008; Roberts 2008; Lowe 2003; Lowe 2004) but not specifically in the VG environment. Therefore, a goal of all VG evaluatory research, including this thesis, should be to investigate how interactivity and dynamism within the media, as well as in the thematic data, affect user knowledge construction processes (Harrower and Fabrikant 2008, 62).

2.4.1 Interactivity in the Virtual Globe Environment

The proactive role of the map reader is perhaps the most noticeable difference between interactive and passive map displays. Through the VG user interface, users control most content and appearance aspects of the displayed data, execute commands (e.g. spinning the globe), and perform actions (e.g. building and distributing thematic datasets). The level of interaction can be simple (zooming to and observing a surface feature) or complex (extracting and analyzing information displayed in the image). In effect, interactivity allows users to control the quality of their individual VG experiences.

Fairbairn et al. (2001, 15-17) cite two aspects of the relationship between a user and an interactive environment warranting special attention. The first is how users interact with user interfaces to control the environment and data, not just manually or visually, but cognitively as well. The second is how users react to and interpret data displayed in an interactive environment. Fairbairn et al. (2001, 16) point out that the study of interactivity is not limited to the relationship between user and application. Issues concerning the selection and use of data appropriate for interactive representation, the impact of interactive representations on both understanding and task outcomes, and how changing technology supports new forms of representation, also necessitate study.

2.4.2 Interactivity and User Performance

As an essential characteristic of the VG interface, interactivity is necessary to control the dynamic content of the display: setting the rotational axis and speed of the globe; selecting the content layers to display; and adding and navigating paths, among others. Lowe (2004) posits users must be able to exercise control of the application in ways "that allow them to locate, extract, and then meaningfully integrate thematically relevant information" (355) in order to build an appropriate mental model of the data under study. To accomplish these tasks in a VG environment, interactivity is fundamental. Harrower and Fabrikant (2008, 54) state that allowing users to make these control adjustments themselves is useful and ethical.

Roberts (2008), however, warns that navigation within a dynamic and 3D environment made possible by interaction presents considerable dangers. Notably, users often get lost in their explorations, especially at large scales, and loss of orientation information can lead to misinterpretation of displayed data. In this regard, Roberts advocates that interactivity be controlled or constrained to minimize user-perpetuated mistakes, and currently, most interactivity is in fact limited to navigational tools and commands, such as tilting, panning, and scaling the perspective view, but minimal dataset creation and placement. The simplicity of design, while credited with augmenting the mainstream success of VGs, also limits their effectiveness as tools for in-depth study of complex subject matter (Lowe 2004, 355).

2.4.3 Dynamism in the Virtual Globe Environment

In contrast to static map displays, VG applications display geographic data in dynamic environments, where features on the globe change with any adjustment to the globe's rotation speed and direction, the perspective view, and the scale of the globe. DiBiase et al. (1992) identified three main types of change in dynamic environments: spatial change, which involves shifts in perspective, scale, and movement; chronological change, which involves the passage of time; and attribute change, which involves re-expressions of the mapped data. VGs are capable of incorporating each type of dynamism in the map display individually or in concert. And while dynamism is not a new map or media capability (for example, animation is often used as a tool for exploratory analysis, such as with time series data or to represent attribute change; see DiBiase et al. 1992; MacEachren 1995), the VG environment is unique for the impact spatial change has on every component of the display.

Because the majority of a globe is always hidden from any single view, a VG cannot operate effectively if its display remains static (although when the VG does not rotate, the display effectively becomes static). The VG's dynamic environment allows limitless variation in spatial change, such that a whole new range of map behaviors is introduced warranting close attention. As spatial change occurs, the appearances of all objects on the map are manipulated in the display, including the characteristics of the visual variables selected to represent the data (Figure 2.4a). To what degree spatial changes affect thematic data representations, and how these changes affect user performance, remain unstudied (Häberling et al. 2008, 178-9, 186).

Figure 2.4a: The prism representing Portugal (in red box) changes appearance as the globe turns. At left, its surface is barely distinguishable from Spain; in the center, Spain obscures Portugal; at right, its prism is clearly visible. © 2011 ESRI.

2.4.4 Dynamism and User Performance

In broad terms, the literature reviewed (for example Dorling 1992; DiBiase et al. 1992; Fabrikant and Goldsberry 2005; Harrower and Fabrikant 2008; Hegarty et al. 2009) shows that dynamism adversely affects users' abilities to comprehend and perceive displayed data. However, the literature *does* indicate that, situationally, dynamic displays (with their ability to affect data attribute or viewing perspective changes) can be more effective than static displays; as Harrower and Fabrikant (2008, 51, 62) show, dynamism is suited to certain kinds of cognitive tasks. Fairbairn et al. (2001, 21-24) summarize multiple uses of dynamism, which can overcome limitations of traditional cartographic methods and facilitate navigation in complex data representations. Andrienko et al. (2008; 2009) discuss the importance of incorporating dynamism into any exploratory tool for investigating and analyzing large or complex datasets, especially spatio-temporal data. Taking into consideration these task suitability issues, now that dynamic map displays such as VGs are common cartographers must determine their effectiveness in specific scenarios, such as cognitive task completion, problem-solving, and decision making (Fabrikant 2005, 1).

Twenty years ago, Dorling (1992, 224) suggested that two essential characteristics of animated (or dynamic) maps were simplicity and extreme clarity. Viewing static maps, Dorling argued, the reader has time to interpret complex or unclear data, whereas the speed of change in animated displays necessitates swift interpretation (or repeated viewings) of the data. To be understood, then, data displayed in a dynamic environment must be simple and clear. Applying Dorling's argument to the VG environment, where the user controls the globe's rotation speed, a similar complication arises. VG users must remember and interpret data as it appears and disappears according to the selected viewing perspective. Hegarty et al. (2009, 182) posit dynamism is often ineffective because changes in maps are difficult for the user to perceive; that is, user perceptual and comprehension processes cannot match the speed of data change.

As an example of how dynamic map displays can adversely affect map reading activities, Fabrikant and Goldsberry (2005, 6-7) investigated change-blindness. This phenomenon, where map readers have difficulty noticing even major changes between successive scenes in an animation, was shown to prevent user coherence of dynamic variables in the map display. Fabrikant et al. (2008) and Harrower and Fabrikant (2008) further examined how dynamic variables influence viewing behavior and whether user control (interactivity) of these variables can improve learning performance. According to these studies, the main problem presented by dynamic displays is the user's inability to remember what is displayed and incorporate it into the larger task of exploring and interpreting the dataset.

Lowe (2004, 355) suggested the possibility of displaying explicit representations of complex and/or multiple layers of changing data in a single view as a potential advantage of dynamic environments. In certain instances this may appear useful (for example, Smith and Lakshmanan 2011; DePaor and Whitmeyer 2011), but the appearance of usefulness does not guarantee that users will understand appropriately the mapped data. As Shepherd (2008) warned about dimensionality, just because dynamism is possible and appears useful does not mean it should be used. Cognition and memory problems caused by dimensionality may be exacerbated by the temporal, attribute, and spatial changes possible in a dynamic environment, particularly the VG environment.

Lowe (2003, 158) noted that many educational materials utilize dynamism wherever possible, based on little more than the assumption that it is superior to staticity. In contrast to this growing preference, Lowe presents well-documented evidence for two situations in which dynamism is actually inferior. In one scenario, the excessive information processing demands of dynamic data overwhelm the user; Lowe warns of a possible split-attention effect in those environments where users must pay full attention to one part of the display at the risk of neglecting information in another area of the display (159). In the second scenario, users focus less on content and do not engage in valuable processing activities in dynamic environments to the extent they would in static environments. Users, especially novice users, are so focused on controlling the dynamic environment that they neglect the content of the display (Lowe 2004, 355). However, these user tendencies do not invalidate the potential of dynamic media such as VGs as tools to augment geographic learning and exploration.

Lowe (2003; 2004) states that, on the basis of his (and other) findings, the potential of dynamism is unlikely to be realized unless appropriately incorporated into existing knowledge structures.

Instead of using dynamic media as default viewing environments for thematic data, cartographers need to identify in which scenarios the confluence of dynamism and thematic data accommodates the user learning process.

2.5 Naive Cartography: Preference Over Performance

Although the disadvantages of utilizing 3D are well-documented, in much of the research a noteworthy trend occurs: test subjects voice a clear preference for 3D displays even when the displays do not facilitate performance and negatively affect their understanding and interpretation of the displayed data (St. John et al. 2001, 79; Hegarty et al. 2009, 172-173). Hegarty et al. termed this phenomenon "naive cartography" and investigated whether users' intuitions about display effectiveness aligned with standard cartographic design principles and the relationship between performance and preference. They found users prefer enhanced, realistic, and detailed 3D maps, and the users tend to expect better performance by using them rather than less-complex, non-realistic maps (Smallman 2005, 7). In practice, however, Hegarty et al. (2009) demonstrate that users prefer and predict better performance from what are actually inferior or unsuitable map displays. Smallman and St. John (2005) suggest that there is a disparity between assumed and actual performance. This stems from fundamental misconceptions about how map users judge the fidelity of their own perceptive powers.

Häberling et al. (2008), repeating Goodchild's (2008) assertion, suggest that the default orthographic "bird's-eye" perspective view of VGs is also the inherent perspective for our human visual system; that is, our mental constructions of the Earth utilize bird's-eye perspectives. If true (neither the literature nor these authors indicate the basis for this assumption), this helps explain why the realistic depiction of the world presented by VGs is so popular and may also help explain the disparity between the prevalence of their use and how well users accurately and effectively understand information displayed on them.

2.6 Applications and Critiques of Virtual Globes

2.6.1 Appeal and Usage Trends

An important reason for the mainstream success of VGs is the success of Keyhole Markup Language (KML), a tag-based scripting language used to create and display 3D geographic data, that is now supported by most major VGs (De Paor and Whitmeyer 2011, 100; Chien and Tan 2011, 39). KML was originally developed in 2004 for Keyhole Earth Viewer, the precursor to Google Earth, and in 2008 Google yielded control of KML to the Open Geospatial Consortium, an international standards organization, guaranteeing its status as the standard file format for digital geographic information (De Paor and Whitmeyer 2011, 100). KML enables users to add custom data to the VG display and interact with and explore the data through user interface controls (De Paor and Whitmeyer 2011, 100).

Several usage trends have emerged in the six years VGs have been widely available. Primarily, VGs are used as general-reference maps for virtual tourism, navigation, and "innocuous voyeurism" (Schoning et al. 2008, 137). High-resolution imagery and intuitive interactivity combine to create a substantial "wow" factor that facilitates these uses (Crampton 2008, 89), but their popularity does not fully extend into the scientific community (Boschetti et al. 2008, 3071). Although increasing amounts of scientific information are accessible to VG visualization, several design properties are believed to limit their analytical effectiveness. As Craglia et al. (2008, 159) suggest, VGs are oriented toward a mass-market rather than a scientific audience, precluding their functionality as tools for scientific investigation. This is at odds with the qualities that appeal to most VG users, specifically the ability to convey shape and depth (St. John et al. 2001, 79) and especially to display the world in a highly realistic manner (Shepherd 2008). Nevertheless, there is an increasing tendency to incorporate more scientific research and visualization (Sheppard and Cizek 2009, 2105), especially as a means to communicate scientific phenomena to wide audiences (Bailey and Chen 2011, 1; Ballagh et al. 2011, 59-60). Ballagh et al. (2011, 57) document many examples of earth scientists distributing material to both scientists and mass audiences for display on VGs, including weather patterns, earthquake activity, polar ice melt, and floodwater rise and retreat. Goodchild (2008, 23) suggests VGs offer enormous potential to social scientists as well, not only as tools to visualize and explore qualitative data, but as a subject of research itself.

The VG's ability to enable exploration of spatial phenomena and enhance science education should not be overlooked (Ballagh et al., 2001, 57, based on Goodchild, 2008). 3D maps are greatly demanded in classroom settings (Häberling and Bär, 2006, 4), and educators are publishing papers describing their educational benefits (Ballagh et al. 2011, 60). The possibility of VGs facilitating students' spatial thinking processes (perceived or proven) point to increased classroom usage. As thematic maps are used to help map readers extract and observe patterns in spatial phenomena, a logical extension of VG use is to use them to display thematically mapped data in the classroom.

2.6.2 Critiques of VGs

Due to the widespread popularity of VGs and the limited fashion in which empirical research dictates appropriate use, the potential exists for serious misuse, misapplication, and misinterpretation of data displayed on them (Goodchild 2008, 23). Sheppard and Cizek (2009, 2107) warn users and researchers that the mass appeal and potential education benefits of VGs do not provide excuses to ignore investigating any and all potential uses or the disparity between expert and non-expert users. Mass-marketed Internet applications, which receive little or no oversight from scientific or expert presenters, satisfy the needs of "average" users who are less likely to possess the knowledge or guidance to create a quality map or to judge the quality of or accurately interpret an existing map; in this scenario, the threat of improper use is considerable (Sheppard and Cizek 2009, 2108-10). Roberts (2008, 41) is one of the few sources to state that published research regarding display capabilities and user performance must be included in the design and implementation of applications from the beginning of development. Roberts also admonishes many geovisualization tool developers for their tendency to “ignore or forget the richness of the published research” (41) and neglect to implement such research into the applications. As the literature shows, cartographers (and many outside the discipline as well) know how the characteristics of the VG environment adversely affect data displays and user performance and recognize that additional research is necessary (Fabrikant and Lobben 2009; Häberling et al. 2008; Hegarty et al. 2009). I, however, found no published efforts to evaluate and address these identified problem areas in a VG setting, confounding efforts within or outside the discipline to establish proper usage guidelines.

The scientific community's reluctance to embrace VGs (Boschetti et al. 2008, 3071) is likely a result of the uncertainty of proper utilization, and it may be that the tasks for which VGs are ideally suited are those uses identified by Schoning et al. (2008): exploration, tourism, and navigation. However, reluctance may stem from the assumptions that VGs cannot adequately display quantitative, scientific data. Opinions of VGs as a medium for displaying thematic data, of which there are few, are largely cautionary (Goodchild 2008, 21) or outright critical (Harrower 2009). In fact, the literature reveals little in the way of support for this particular use, and those who are advocates do not present supporting evidence (Sandvik 2008, 6; Kraak 2001, 67). Harrower (2009), drawing on the work of notable cartographers Arthur Robinson, Alan MacEachren, and Borden Dent, clearly states the two basic uses of thematic maps: 1) to extract specific data about specific locations; and 2) to observe the overall patterns of those data. As examined in the cartographic literature, several characteristics of VGs prevent fulfilling either use adequately. VGs are not capable of displaying global datasets in a single view. Further, accurate interpretation of displayed data is hindered by the constant perspective and scale changes necessary to view the entire dataset.

2.7 Summary: The place of VGs in cartography

If empirical research determines VGs are a suitable medium for thematic mapping, researchers must then establish whether existing design principles for matching visual variables to thematic data are applicable in VG environments; if existing principles are non-applicable, or *situationally* applicable, then this must also be empirically determined. Harrower and Fabrikant (2008, 49) warn of the danger of mapping technology outpacing cartographic design theory, and Harrower (2007, 349) also warns it can also outpace the capabilities of the map readers for whom the technology was designed. Either situation could result in the widespread use of VGs to complete tasks for which they are ill-equipped to handle, difficult to understand, and thus largely ineffective. Empirical research that yields effective design principles can prevent these problems and enhance a user's experience. A key component of this thesis is to contribute to the burgeoning research examining virtual globes as thematic mapping media and possibly assist the establishment of such guidelines.

Since the essence of cartography is to abstract data and phenomena from the real world and create map displays that maximize information saliency while minimizing extraneous clutter (Hegarty et al. 2009, 172), successful design for and performance in the VG environment depends on the user's knowledge and intuition about which displays are most effective and which display configurations are effective or ineffective for different tasks (Hegarty et al. 2009, 172), but most (if not all) VG applications do not provide tutorials or instructions for high quality map creation. Goodchild (2000, 10-11) emphasizes this paradox, rhetorically asking, "In a world in which everyone can make a map, who needs cartography?" while pointing out that the need for good cartographic design is stronger than ever. This may be especially true for VGs as they are widely used by casual and non-professional cartographers.

The literature suggests cartographers should be wary in utilizing VGs solely for their realistic, 3D environment. Shepherd (2008, 200) common-sensically warns that just because something can be done does not mean it should be done; this tendency may very well become an arbitrary "VG for VG's sake" decision among professional and non-professional map-makers alike. The capability to display thematic data is already built into VGs, so the challenge is not just to reconsider their use (although, as per Shepherd (2008, 200), it may be too late for that) but to guide or temper their designation as the default viewing environment for all geographic data.

CHAPTER 3: METHODS

3.1 Experimental Strategy and Goals

This thesis analyzed user performance and user preference in the realm of VGs used for thematic mapping. User performance was evaluated based on reading accuracy, reaction times, and memorization of data by comparing VGs using thematic 2D symbolization (choropleth maps) and 3D symbolization (prismatic maps) with traditional 2D maps using the same two symbolization methods, and by displaying different thematic datasets on each. An exit questionnaire gathered opinions on user preference of map and symbolization type and required users to assess their own performance. This strategy was shaped to meet several goals of the study:

1. To evaluate how well users acquire, interpret, and retain thematic data displayed on VGs.

2. To evaluate user performance when utilizing 2D versus 3D symbolization in both traditional 2D and VG environments.

3. To investigate user preference among map medium-symbolization combinations and assess if level of preference matches quality of performance.

3.2 Design Conditions

The experiment was designed to address each of the stated goals and test each of the four hypotheses stated in Chapter One. The data necessary to analyze user performance and preference were collected through the administration of tests composed of four different map medium and symbolization combinations. The two map mediums were a traditional 2D "flat" map and a VG; the two thematic symbolization methods were 2D choropleths and 3D prisms. (Figure 3.2a).

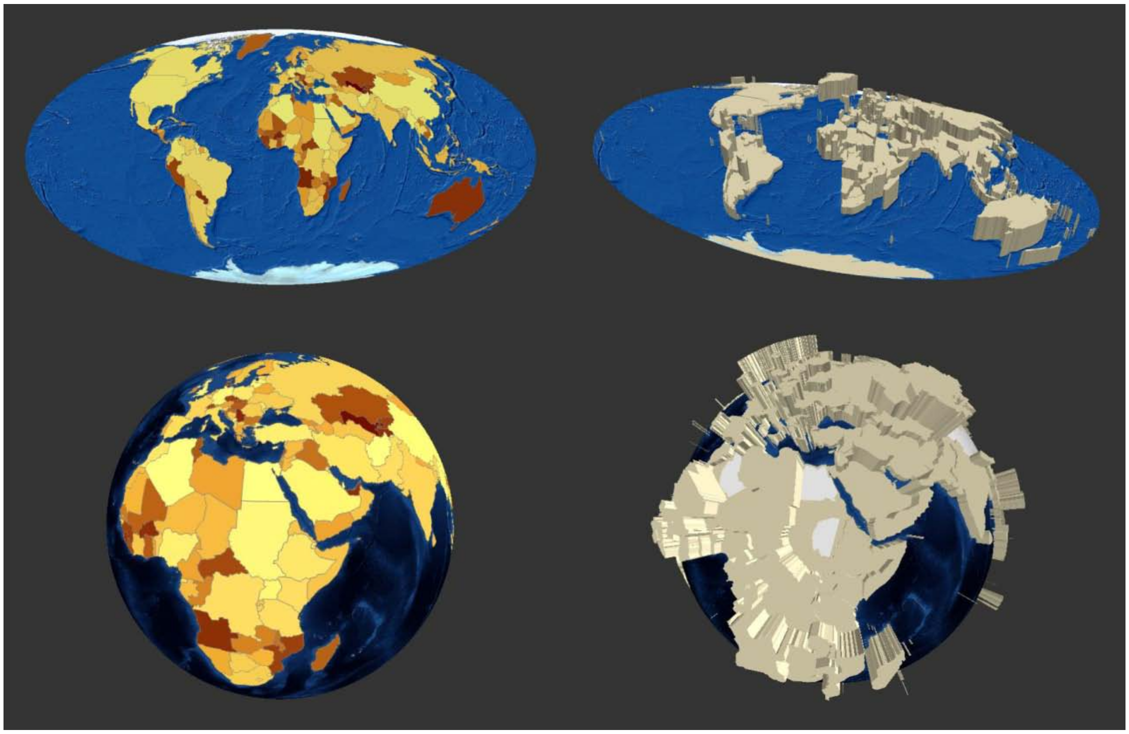

Figure 3.2a: Examples of the experiment maps. Clockwise from top-left: choroplethic flat map, prismatic flat map, prismatic virtual globe, choroplethic virtual globe. Scale is not consistent between the flat maps and virtual globes. Basic scale controls for both ArcScene and ArcGlobe (the mouse scroll wheel or zoom tool) are imprecise. © 2012 ESRI.

3.2.1 Test Tasks and Question Types

Each participant viewed four maps in order to complete a series of tasks. Each map contained a different dataset to ensure that no duplication of datasets or map medium-symbolization method combinations occurred in any test session. Each participant observed, analyzed, and provided feedback on each map variable (flat map, virtual globe, choropleth, prism) under study. The tests consisted of four tasks per map, three measuring data acquisition accuracy and one evaluating memorization accuracy. The four tasks were as follows:

1. *Highest Value Identification Task.*

Participants identified the country displaying the highest value within each dataset or a specified region.

2. *Value Estimation / Equal Value Identification Task.*

Participants identified a data value approximately equal to a predetermined value displayed on the screen.

3. *Data Range Variance Task.*

Participants estimated data ranges and identified regions displaying the greatest variance in data values.

4. *Memorization Task.*

The computer window displaying the map was closed, and participants recalled general data (such as the region displaying lowest variance) and specific data (such as the data value of a specific country).

3.2.2 Map Creation and Display

A traditional 2D map displayed in ESRI ArcScene and a VG displayed in ArcGlobe were the two map mediums. For the 2D map, a Mollweide equal-area projection was utilized for its accurate display of area; all area on this projection is proportional to area on the virtual globe when both are at the same scale. ArcScene is an interactive application that can display both 2D and 3D symbolization on a 2D map and that allows users to manipulate the viewing angle of the map. The ArcGlobe user interface contains the same interactive viewing characteristics as ArcScene, plus additional controls to manipulate the rotation angle and speed of the globe. In all, a total of sixteen maps were created using a combination of the two mediums, two symbolization methods, and four datasets.

Thematic datasets were initially imported into and manipulated in Microsoft Office Excel 2007, then imported into and joined to identical vector shapefiles in ArcScene and ArcGlobe. All computer-displayed maps in the study were created and viewed through ArcScene and ArcGlobe. ArcGlobe was selected for this study for two important reasons: first, with the exception of dimensionality, the data display of this VG is identical to the data display of ArcScene (including color, icons, text, and window frames); second, the applications share the same basic navigational controls (pan/move, navigate/tilt, and zoom), and these controls are also representative of those used by all other major VGs.

3.2.3 Symbolization and Color Scheme

Certain graphic variables, such as color, shape, and size, were used in thematic mapping to differentiate between categories and quantities of data. Choropleth mapping may employ one or more of these visual variables. In these experiments, a combination of hue and lightness were used to assign specific data values to each enumeration unit. In general, light colors/shades are utilized for low data values and dark colors/shades for high data values (Robinson et al. 1995; Dent et al. 2009; Krygier and Wood 2005). The default algorithmic color chart assigned to graduated color quantities in ArcGIS (low value CMYK = 5,35,82,0; high value CMYK = 58,100,100,0) was utilized in this experiment. Those observations for which data was unavailable were assigned a schematically different color to avoid confusion with existing observations.

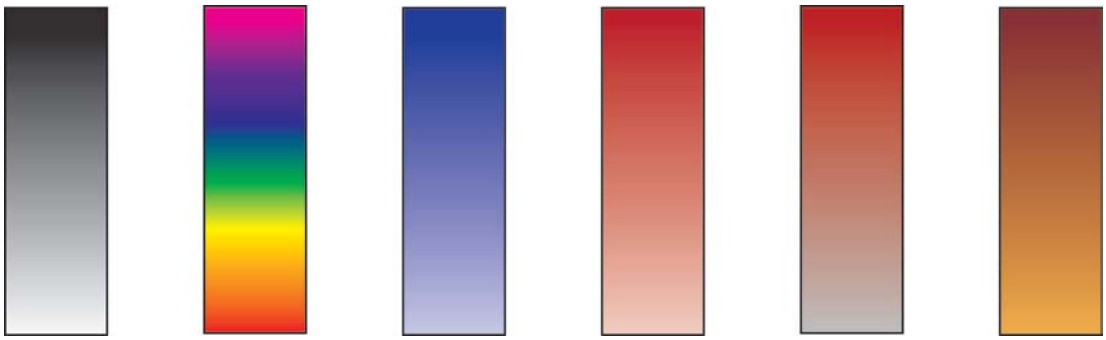

Figure 3.2b: Examples of thematic data color charts. Left to right: value/brightness; spectral; cool; warm; saturation; and the warm multi-hue colors used in this experiment.

Prismatic maps use the visual variable perspective height to quantify individual data values (short prisms are utilized for low data values, tall prisms for high data values). Prism heights were calculated and assigned by the Extrusion setting in ArcScene, wherein a selected data attribute is inserted into a mathematical expression which transforms the enumeration units into blocks that extrude from the map surface. The heights were directly proportional to the data.

3.2.4 Classification Scheme

Different methods of data classification are used by cartographers to optimize data acquisition, depending on the purpose of a particular map. Classed maps involve combining observed data values into a predetermined number of groups or classes, each represented by an equal number of color shades. Unclassed maps do not group the data, and all observed values are represented by unique color shades (Slocum et al. 2009, 57). The datasets used in these experiments remained unclassed so that the full range of data values were viewable on the map and all numerical relations between the values were maintained. It was particularly important for these experiments that the prismatic maps remained unclassed in order to test whether estimating prism heights proportional to their actual data values was enhanced in the 3D environment of VGs, to ensure each dataset included one value that was larger than all others, and to emphasize their distinctive 3D appearance in the VG environment. The choropleth map data were also unclassed so that color values were proportional to actual data values, and the maps maintained some thematic consistency.

3.3 Participants

The target population (the entire population under study) is comprised of all VG users. The working population (the accessible portion of the target population) is comprised of all graduate and undergraduate students enrolled at the University of Kansas. However, the actual working population of this research was comprised of geography and non-geography students enrolled in courses within the Department of Geography, which limited the applicability of these results as being truly representative of the target population.

Participants consisted of 52 graduate and undergraduate students enrolled in 100-level, 300-level, 500-level, and 700-level geography courses. 92 percent of these participants were undergraduates, 39 percent were geography majors, and exactly half indicated they had prior mapping experience. The ages of participants ranged from 18 to 52 ($\bar{x}$ = 22.64), with 12 females and 40 males; the disproportion between sexes was in part due to there being fewer female than male geography majors. The research attempted to account for all levels of geographic, cartographic, and VG experience. All participation was voluntary and unpaid.

3.4 Expected Results & Predictions

The research highlighted in the literature review (e.g., Hegarty et al. 2009; Harrower and Fabrikant 2008) indicated that map analysis and interpretation tasks become increasingly difficult as the dimensionality, interactivity, and dynamism of the map variables under study increase. Additionally, the literature pertaining to map reader preference for complex displays and the occurrence of "naive cartography" (St. John et al. 2001; Smallman 2005; Hegarty et al. 2009) indicates that preference for complex map displays are inversely related to map knowledge and familiarity (that is, casual or infrequent map users will prefer maps exhibiting greater dimensionality, interactivity, and dynamism, and knowledgeable map users will prefer maps exhibiting less). The following predictions are based on these findings, which were incorporated into the experiment design and tested through the four hypotheses.

3.4.1 User Performance and Map Complexity Predictions

The first prediction was that user performance, determined by correctness-of-response and value estimations, will be noticeably better in maps exhibiting less display complexity (dimensionality, interactivity, and dynamism). As discussed, the literature (e.g. Lowe 2003; Harrower and Fabrikant 2008; Roberts 2008; Hegarty et al. 2009) indicated that tasks completed in perceptually complex environments (increased dimensionality, dynamism, and interactivity) would result in poorer participant performances than those completed in less complex environments.

3.4.2 User Performance and Literacy Predictions

It was expected that performance could be explained in part by the map reading skills (cartographic, geographic, and graphic literacy) possessed by each participant. Based on this expectation, it was predicted that high map reading skills would account for superior performances and low (or an absence of) map reading skills would account for inferior performances.

3.4.3 Completion Times and Map Complexity Predictions

As stated in the hypothesis section, increases in map display complexity (increased dimensionality, interactivity, and dynamism) are expected to result in greater completion times. It was predicted that participants would record their shortest completion times using the least complex map display in the experiment (the flat-choropleth map combination) and the longest completion time using the most complex map display in the experiment (the virtual globe-prism map combination).

3.4.4 Naive Cartography: User Preference, User Performance, and Map Effectiveness

Based on the principle of naive cartography, participants were expected to indicate the strongest preference for the most complex map display (the virtual globe-prism map combination) and the weakest preference for the least complex map display (the flat-choropleth map combination). Additionally, participants were expected to rate complex map environments more favorably than less-complex map environments regardless of how well they performed in either environment or which map combination they preferred.

3.5 Materials

3.5.1 Hardware

The study was conducted on a Dell Optiplex 780 and a Dell P2210H 21.5-inch flat panel widescreen monitor with a 1280 x 1024 screen resolution. The color brightness and contrast settings remained at default levels, 0 and 50 respectively.

3.5.2 Software

The software used for this study was Microsoft Office Word 2007 (Microsoft Corporation, 2007), ArcGIS 10 (Environmental Systems Research Institute, Inc., 2010), Adobe Illustrator CS4 (Adobe Systems, Inc., 2008), and Adobe Acrobat 9 Pro (Adobe Systems, Inc., 2009). Word was used to create all printed test material, including consent forms, surveys, answer sheets, and post-test questionnaires. Two ArcGIS extensions, ArcScene and ArcGlobe, were used to create and display each map in the experiment; ArcScene was used to display flat maps in both 2D and 3D environments, and ArcGlobe, ESRI's virtual globe application, was used to display both virtual globe maps. Illustrator was used to create the reference map and legend displayed throughout the experiment. Acrobat was used to display on-screen instructions and questions.

3.5.3 Data

Maps displayed one of four ratio-level datasets created specifically for this test. A Geographic Information System (GIS) shapefile of world countries was acquired from the University of Kansas Libraries GIS and Data Lab; each country polygon in the shapefile was randomly assigned an integer value between 0 and 90, after which one country was randomly selected and its integer value was changed to 100. The data values were left unclassed. This process was repeated three times, resulting in four unclassed datasets (Appendix J) whose values, ranging 0 to 100, were proportionally comparable, and whose highest-value countries were visually distinguishable using either symbolization method. An additional benefit of using unclassed data was that any existing outliers would result in striking visual differences among data values, especially those represented by prisms. These differences were desirable to maximize the 3D display capability of the VG environment.

3.6 Test Procedure

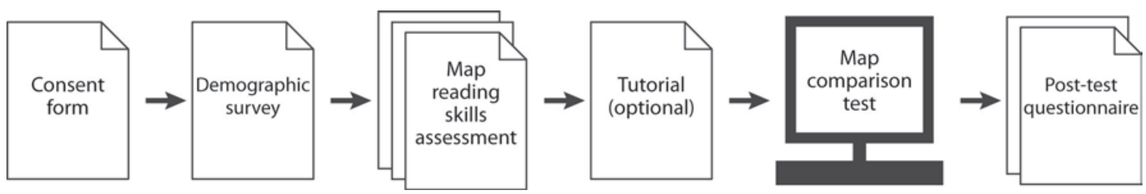

Figure 3.6a: Flowchart of the test components in order of occurrence.

All participants followed the same testing procedure (Figure 3.6a). First, participants were given two copies of a consent form (Appendix A), one to sign and return and one to keep for their own records. Second, the participants completed a demographic information survey (gender, age, year in school, etc.). In an effort to assess their map reading skills, participants also completed geographic literacy (maps labeling) and cartographic literacy (sample thematic data value estimation) exercises. An exercise designed to assess participant graphic literacy was also collected; however, while potentially useful, the results did not yield enough data to be of use in this research. Next, participants unfamiliar with common Internet mapping applications (e.g., Google Maps or Google Earth) were provided a brief hands-on demonstration of the relevant user interfaces of the software. These controls, all performed using the computer mouse, consisted solely of zooming (changing the map scale), panning (changing the focal point of the map and controlling VG rotation), and tilting (changing the angle of the display perspective). All computer mice were equipped with a scroll wheel. Then the main test consisting of four map medium-symbolization combinations was conducted, followed by a questionnaire asking the participants to evaluate each map. When the questionnaire was complete, participants were dismissed.

The experiment was completed in the Geographic Information System and Information Processing computer lab in 310 Lindley Hall at the University of Kansas, Lawrence campus. Each participant spent approximately twenty-five minutes completing the tutorial, test, and necessary documentation.

3.6.1 Pretest Literacy Assessments

Prior to the main test, participants completed a three-page survey designed to evaluate their basic geographic, cartographic, and graphic literacy abilities (Appendix B). The purpose of each assessment was to determine each participant's basic literacy levels and use the results to help explain performance and preference data. The geographic literacy survey was based on the assumption that all University of Kansas students would be familiar with major continents and the states neighboring Kansas; the cartographic literacy survey was based on established cartographic design principles (e.g. Krygier and Wood 2005; Slocum et al. 2009); and the graphic literacy survey was based on prior research conducted by Carroll (1993) and Hegarty (2004).

3.6.2 Tutorials and Instructions

At the start of each test session, participants were provided with a short tutorial (Appendix E) to explain the basic user interface controls of the software applications in use (ArcScene and ArcGlobe). The experiment tasks were designed to ensure the only hardware necessary to complete the test was the computer mouse. A set of instructions to complete all test tasks as well as a legend describing basic application controls were displayed on-screen for the duration of each task.

3.6.3 Main Test Tasks

As described above, participants viewed four maps and completed four tasks per map for a total of sixteen tasks per test session (Appendix C). Prior to viewing each map, participants were instructed to spend up to one minute exploring the map in order to familiarize themselves with the distribution of data; when the participants indicated they were ready to view the map, the map was displayed on screen and the time spent exploring was recorded. Exploration ended when the participant turned the test page to the first task question, which also marked the start of the first task completion time. Each task completion time started when participants displayed the task question and ended when they turned the page to the next task question. After the third task, the display instructed participants to once again spend up to one minute exploring the map before closing the map window and turning the page to answer two memory-based questions; this exploration time started when the participants displayed the instructions and ended when they closed the map window. The memory task completion times started when the participants displayed the memory-based questions and ended when they indicated they were finished answering the questions. Task times were recorded by the researcher. This procedure is visualized in Figure 3.6b.

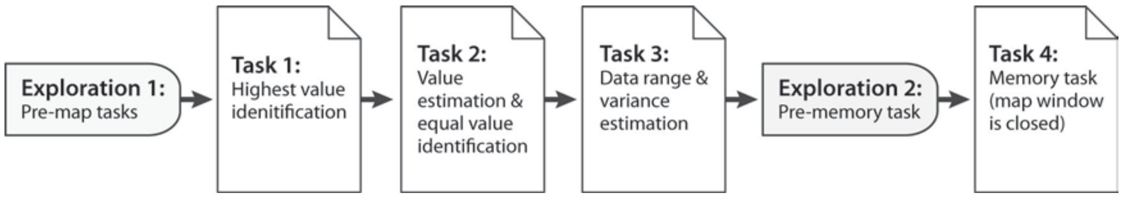

Figure 3.6b: Flowchart showing the order of map exploration and test tasks per map combination.

3.6.4 Questionnaire

At the end of each session, participants completed a written questionnaire (Appendix D) that collected demographic data and asked them to identify their preference for each map medium, symbolization method, and medium-symbolization combination, and also rank the four map combinations in order of preference. Participants were also instructed to rate the effectiveness of each map variable and map variable combination along a Likert scale where 1 = lest effective and 5 = most effective. Evaluation of these responses allowed comparisons among participants' preference of each map medium and symbolization method combination, how participants think they performed using each combination, and how they actually performed using each combination.

Chapter 4: Results and Analysis

Separate statistical procedures utilizing SPSS software were used to analyze the accuracy of the data acquisition and memorization tasks and the completion times of those tasks. An alpha level of .05 was used for all statistical tests. Complete data tables are located in Appendices F — H.

4.1 User Performance: Accuracy

The 16 tasks included in the experiment utilized three kinds of user performance data for evaluation: accuracy, or correctness-of-response, data; value estimation precision data, or how well participants were able to estimate a specific value or range of values; and correctness-of-response data based on memory recall. Of these 16 tasks, 12 were completed while viewing a map, and the remaining four were memory-based, completed only after the computer map display was closed. The analysis of accuracy was approached using several interrelated comparison tests. Accuracy rates were evaluated using paired samples t-tests and repeated measures analysis of variances (ANOVAs), and the value estimation data was evaluated using two-way ANOVAs.

4.1.1 Overall Participant Accuracy Results

In this study, correctness-of-response data was composed of participant answers to the 17 correct/incorrect questions. Overall, the mean test score was 57.2%, or 9.72 out of 17 questions answered correctly; the highest participant score was 15 of 17 correct answers, and the lowest scores was 2 of 17 correct answers ($n = 50$, $\bar{x} = .572$, $s = .150$). The histogram of total correct responses by participant appeared normally distributed, an observation confirmed by a Shapiro-Wilk test for normality ($p = .217$).

A comparison of the accuracy rates among the twelve non-memory-based questions and four memory-based questions shows mean performance was higher for non-memory-based tasks (Table 4.1a). A review of corresponding histograms (Figure 4.1a) shows the distribution of each are dissimilar; non-memory-based accuracy rates are non-normally distributed almost entirely in the upper half of the scoring scale, whereas the memory-based accuracy rates are normally distributed across the entire scoring scale.

	n	$\bar{x}$	s	Minimum	Maximum	Shapiro-Wilk sig.
Overall Accuracy Rate	50	.572	.150	.118	.882	.217
Non-Memory-based	50	.650	.161	.100	.900	.001
Memory-based	50	.460	.209	.000	.857	.022

Table 4.1a: Overall, memory-based, and non-memory based accuracy rates.

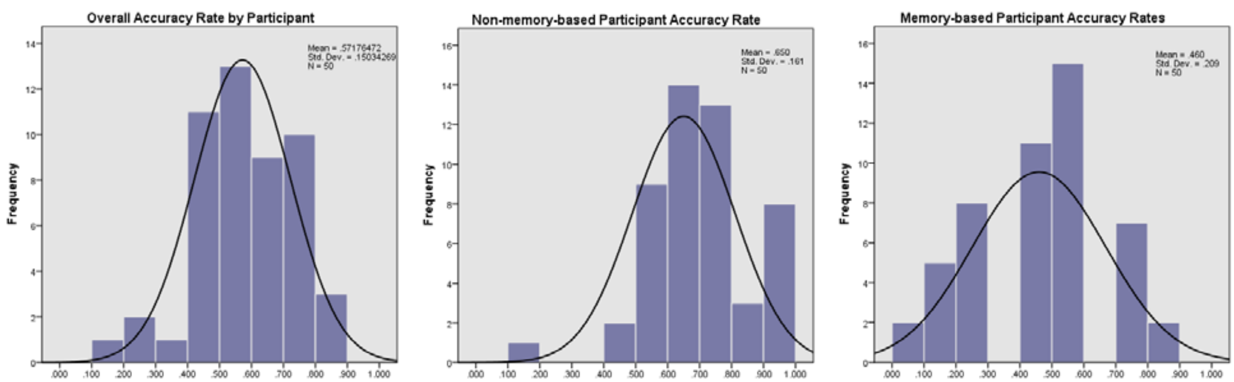

Figure 4.1a: Histograms of overall (left), non-memory-based (center), and memory-based (right) accuracy rates by participant.

A paired samples t-test was performed to compare the means of memory-based and non-memory-based accuracy rates. There was a significant difference in the scores for non-memory-based accuracy rates ($\bar{x}$ = .650, s = .161) and memory-based accuracy rates ($\bar{x}$ = .460, s = .209); $t(49) = 6.447$, $p = .000$, with participants scoring higher on non-memory-based questions. Based on these analyses, for the remainder of this section memory-based user performance is evaluated separately from non-memory-based user performance.

4.1.2 Overall Participant Accuracy and Dimensionality

The hypothesis that map dimensionality affects user performance was evaluated by comparing overall participant accuracy rates with the map variables (map medium and symbolization method). Recall that each participant viewed all four map variable combinations to answer the same number of test questions. Table 4.1b summarizes these results, and the distributions of each accuracy rate by map combination is displayed in the corresponding histograms (Figure 4.1b).

Map Combination	*n*	$\bar{x}$	*s*	Minimum	Maximum	Shapiro-Wilk sig.
Flat – Choropleth	49	.813	.254	.000	1.000	.000
Flat – Prism	50	.567	.342	.000	1.000	.000
Globe – Choropleth	50	.713	.278	.000	1.000	.000
Globe – Prism	50	.507	.342	.000	1.000	.000

Table 4.1b: Mean participant accuracy rates separated by map variable combination.

Participants answered more questions correctly using the flat map-choropleth variable combination ($\bar{x}$ = .813) than any other variable combination, and the distribution of raw scores shows extreme negative skewness (over half of the participants correctly answered all questions based on the flat-choropleth map). The next highest mean accuracy rate was logged by the choroplethic VG ($\bar{x}$ = .713), and the distribution of scores is also negatively skewed. The accuracy rates of the two prismatic maps, prismatic flat maps ($\bar{x}$ = .567) and prismatic VGs ($\bar{x}$ = .507), appear more evenly distributed across the scoring range (although they are still non-normal).

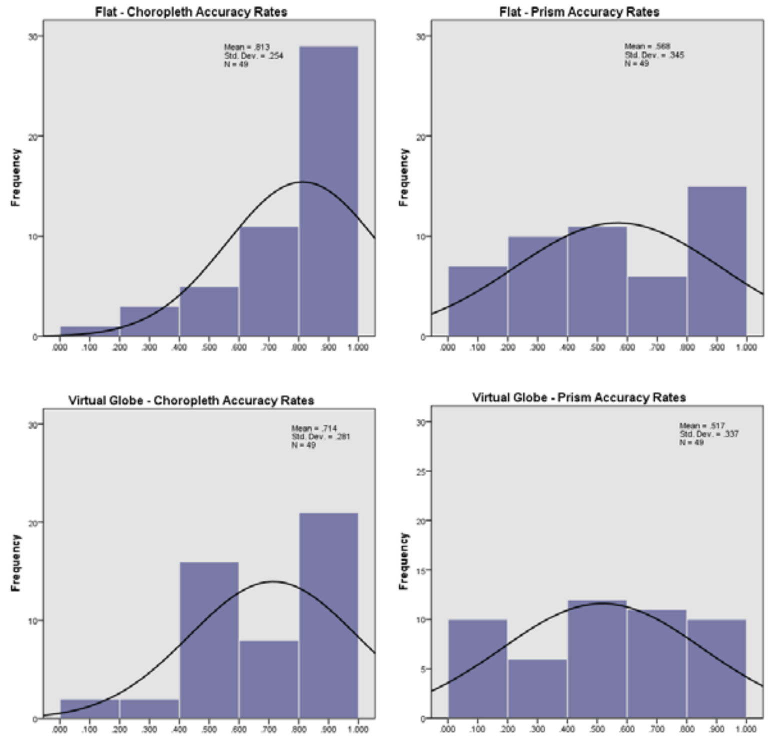

Figure 4.1b: Histograms of accuracy rates by map variable combination. Clockwise from upper- left: Flat-Choropleth, Flat-Prism, Virtual Globe-Prism, and Virtual Globe-Choropleth.

A repeated measures ANOVA was conducted to compare the effect of each map variable combination on overall participant accuracy rates using the four map combination conditions. The Within-Subjects Effects test results indicated a statistically significant interaction effect between map medium and symbolization method, $F(1, 49) = 5.184$, $p < .05$, partial $\eta^2 = .096$; this revealed that accuracy rates increase as map variable combination dimensionality decreases, and the rates decrease as combination dimensionality increases. Map medium did not have a significant main effect on accuracy rate, $F(1, 49) = 1.313$, $p = .257$, partial $\eta^2 = .026$. Symbolization had a significant main effect, $F(1, 49) = 23.454$, $p < .000$, partial $\eta^2 = .324$; note the magnitude of the symbolization effect size, which according to partial eta squared implied that symbolization method accounted for nearly 33% of the overall variance within the sample. Post hoc tests using the Bonferroni adjusted comparisons of factor interactions revealed that mean participant accuracy rates using choroplethic maps of either medium are all higher than mean accuracy rates using prismatic maps of either medium, and three out of those four differences were statistically significant (Table 4.1c and Figure 4.1c). These results suggest that, of the two map variables, symbol dimensionality is the only indicator of participant accuracy rates: participants achieve a higher accuracy rate using maps with 2-D choropleth symbolization and achieve lower accuracy rates using maps with 3-D prism symbolization.

Bonferroni Comparison for Accuracy Rates by Map Variable Combination

Comparisons	Mean Accuracy Rate Difference	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Flat – Choropleth vs. Flat – Prism	.245**	.054	.095	.394
Flat – Choropleth vs. Globe – Prism	.296**	.060	.130	.462
Globe – Choropleth vs. Flat – Prism	.146	.067	-.038	.330
Globe – Choropleth vs. Globe – Prism	.197**	.030	.013	.381

** $p < 0.05$

Table 4.1c: Bonferroni pairwise comparisons of map variable combinations.

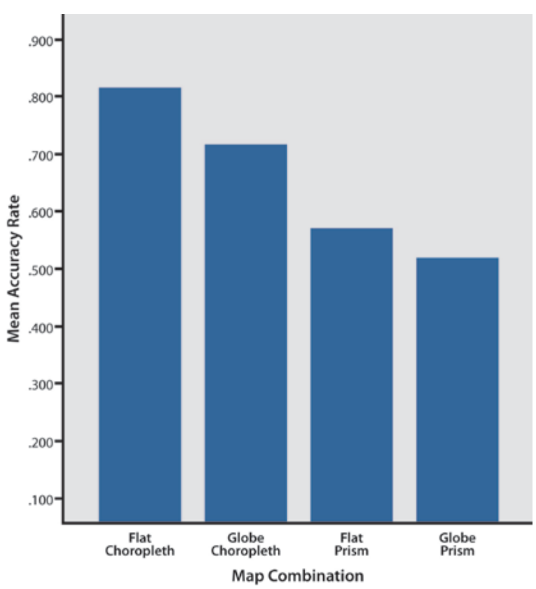

Figure 4.1c: Bar chart displaying mean accuracy rates by map variable combination.

4.1.3 Overall Value Estimations and Dimensionality

Value estimation was also used to test the hypothesis that increases in map dimensionality negatively affects user performance. Five non-memory based test questions required participants to estimate a choroplethic or prismatic ratio value or range of values displayed on a map. Response accuracy was measured by subtracting the estimated value from the true value, with a score of zero indicating a correct estimation. The differences of these data were expected to be normally distributed around a mean of zero.

Table 4.1d summarizes these results, and the distributions of each value estimation by question is displayed in the corresponding boxplot (Figure 4.1d). For three of the questions, 1.2b, 2.2b, and 4.3, the means are close to scores of zero. The value estimation distributions for three questions, 1.2b, 3.3, and 4.3, are non-normally distributed around their means; the distributions of 1.2b values estimations are tightly clustered around the mean (Kurtosis = 5.735), the distribution of 3.3 value estimations are negatively skewed by multiple low outliers, and the distribution of 4.3 values are both clustered around the mean (Kurtosis = 2.927) and affected by high and low outliers.

	n	$\bar{x}$	s	Min. Difference	Max. Difference	Shapiro-Wilk sig.
Question 1.2b	42	-1.95	10.83	-43	31	.000
Question 2.2b	45	1.33	14.70	-32	38	.018
Question 3.2b	42	7.02	23.42	-65	73	.013
Question 3.3	50	-8.14	15.21	-48	18	.009
Question 4.3	50	3.58	13.73	-33	49	.001

Table 4.1d: Descriptive statistics of mean value estimations by individual question.

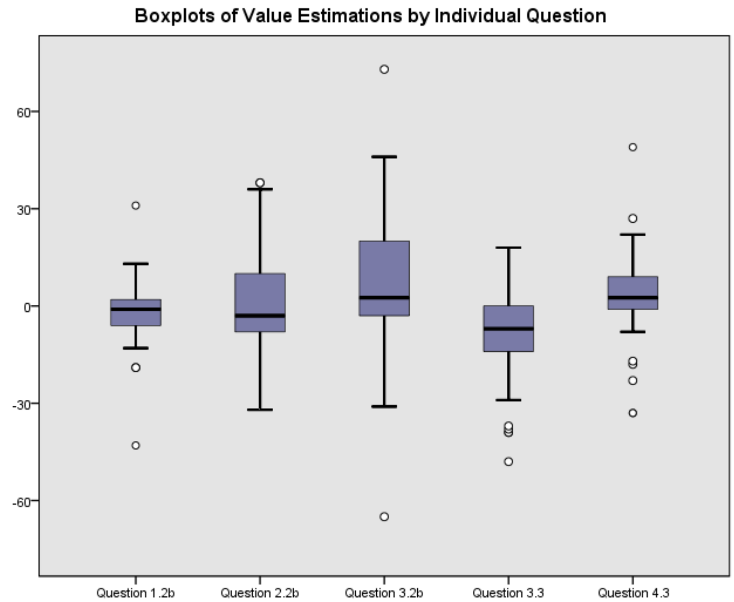

Table 4.1d: Distribution of value estimations by individual question.

Next, two-way ANOVAs were conducted for each question to investigate the relationship between value estimations and both of the map variables. The ANOVA results for just one question, 2.2b, indicated a significant main effects for the map medium, $F(1, 41) = 5.186$, $p < .05$, partial $\eta^2 = .112$, and symbolization method, $F(1, 41) = 6.172$, $p < .05$, partial $\eta^2 = .131$, and that the interaction between factors was not significant, $F(1, 41) = .462$, $p = .501$, partial $\eta^2 = .011$. The calculated effects size for each factor indicates a small proportion of value estimation variances are accounted for by medium and symbolization dimensionality, and even then in just one of the five value estimation questions. Other than for question 2.2b, the ANOVAs did not indicate any statistically significant relationships between value estimations and map variable dimensionality.

4.2 User Performance: Accuracy Sorted by Demographic Data

The section 4.1 analyses results indicate two outcomes regarding participant accuracy rates and map variable dimensionality:

1. Overall differences in participant accuracy rates are not independent of symbolization method and the interaction of map medium and symbolization method, but they are independent of map medium.
2. Differences in participant value estimations are independent of both map variables or some combination thereof.

However, the map variables alone were not expected to account for all differences in user performance. Hypothesis two of this research posits that users possessing superior cartographic, geographic, and graphic literacy will perform more accurately than those possessing inferior cartographic, geographic, and graphic literacy, and so participant characteristics potentially influencing performance were collected through the demographic survey and pre-test questionnaire (Appendix B). This section assesses these shared characteristics to determine which, if any, act to influence user performance.

4.2.1 Participant Demographics and Accuracy Rates

Six participant characteristics were identified as relevant to hypothesis two: 1) major of study, 2) past or present enrollment in a cartography course, 3) previous mapping experience, 4) geographic literacy, 5) cartographic literacy, and 6) English literacy. Independent samples t-tests were conducted to investigate the relationships between each of these characteristics and overall accuracy rates. Of these variables, the effects of just three tested statistically significant: English literacy, geographic literacy, and mapping experience.

English proficient participants had higher mean accuracy rates ($\bar{x}$ = .668, *s* = .143, *n* = 44) than participants not English proficient ($\bar{x}$ = .517, *s* = .232, *n* = 6). Although the t-test results for English literacy were statistically significant, $t(48) = -2.26$, $p < .05$, as all test materials were written and displayed in English, these results were not unexpected, and English literacy as an indicator of accuracy rates was noted but not analyzed any further.

Participants displaying any evidence of geographic illiteracy in the pretest assessment or during the test achieved a lower mean accuracy rate ($\bar{x}$ = .555, *s* = .175, *n* = 11) than those exhibiting geographic literacy ($\bar{x}$ .677, *SD* = .148, *n* = 39). The t- test results were statistically significant, $t(48) = -2.33$, $p < .05$, indicating that participants possessing geographic literacy were significantly more likely to answer questions correctly than participants who demonstrated geographic illiteracy. A repeated measures ANOVA test was conducted to examine the interaction effects of geographic literacy, map medium, and symbolization method on participant accuracy rates (Appendix F); the Within-Subjects Effects results indicated no significant interaction effects existed between the DV and IVs. This suggests that the lower accuracy rates of geographically illiterate participants was independent of map dimensionality changes.

Participants possessing previous mapping experience achieved a higher mean accuracy rate than those without previous mapping experience (Table 4.2a), which suggested that mapping experience is an indicator of user performance. The result of the t-test examining this relationship was statistically significant, $t(48) = 2.195$, $p < .05$, indicating that accuracy rates are not independent of mapping experience, and that participants with mapping experience achieved a higher mean accuracy rate than participants without mapping experience.

	n	$\bar{x}$	s	Minimum	Maximum	Shapiro-Wilk sig.
Mapping experience	26	.696	.151	.400	.900	.039
No mapping experience	24	.600	.159	.100	.900	.005

Table 4.2a: Descriptive statistics of accuracy rates by mapping experience.

4.2.2 Mapping Experience, Accuracy Rates, and Dimensionality

Having confirmed that a relationship exists between mapping experience and accuracy rates, and in particular that having prior mapping experience is an indicator of improved user performance, the next step involved comparing those conditions with dimensionality to determine which, if any, of the map variables affect the participant groups in different ways, either in combination or separately.

The mean accuracy rates of participants (Table 4.2b) across all four map combinations, separated by mapping experience, suggested that participants lacking mapping experience generally performed worse than participants with mapping experience, particularly when using either prismatic map (flat-prism mean difference = .202, globe-prism mean difference = .155). A review of each boxplot (Figure 4.2a) displaying accuracy rates by map combination supported this suggestion, showing the general distribution of accuracy rates between groups to be approximately similar for the choroplethic maps and dissimilar for the prismatic maps. Also note that the overall accuracy of both groups decreased as map dimensionality increased.

	Experience	*n*	$\bar{x}$	*s*	Minimum	Maximum	Shapiro-Wilk sig.
Flat - Choropleth	Yes	25	.847	.240	.333	1.000	.000
	No	24	.778	.268	.000	1.000	.000
Flat - Prism	Yes	25	.667	.354	.000	1.000	.001
	No	24	.465	.311	.000	1.000	.012
Globe - Choropleth	Yes	25	.727	.280	.000	1.000	.001
	No	24	.701	.287	.000	1.000	.000
Globe - Prism	Yes	25	.593	.316	.000	1.000	.011
	No	24	.438	.347	.000	1.000	.003

Table 4.2b: Descriptive statistics of accuracy rates by map combination and mapping experience.

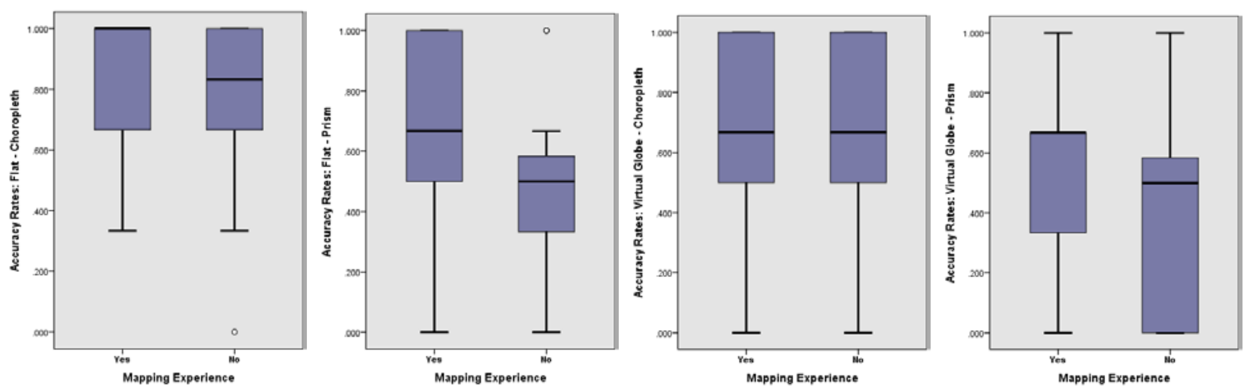

Figure 4.2a: Boxplots of accuracy rates by map combination and mapping experience.

A repeated measures ANOVA was conducted to examine the effect of mapping experience on overall participant accuracy rates across the four map combinations. The Within-Subjects Effects test results indicated a statistically significant interaction between mapping experience and symbolization method, $F(1, 48) = 5.377$, $p < .05$, partial $\eta^2 = .101$, but no significant interaction between mapping experience and map medium, $F(1, 48) = .033$, $p = .857$, partial $\eta^2 = .001$, or between mapping experience, map medium, and symbolization method, $F(1, 48) = 1.171$, $p = .285$, partial $\eta^2 = .024$. Two independent samples t-tests were used to make post hoc comparisons between mapping experience and accuracy rate, one test for each symbolization method. The choropleth t-test results indicated no significant difference in the accuracy rates of participants with or without mapping experience; $t(48) = -.834$, $p = .409$. The prism independent samples t-test indicated a statistically significant difference in the accuracy rates of participants with mapping experience ($\bar{x}$ = .604, s = .241) and participants without mapping experience ($\bar{x}$ = .460, s = .214); $t(48) = 2.083$, $p < .05$.

These results, visualized in the profile plots (Figure 4.2b), support the indication that significant accuracy rate decrease is an effect of symbolization dimensionality increases, and that the severity of decrease is different between the groups (Table 4.2c). Although the accuracy rates of participants with mapping experience decreased as dimensionality increased from 2D to 3D (mean difference = .118), the decrease was much larger for participants without mapping experience (mean difference = .316). This in turn supports the hypothesis that participants possessing superior cartographic and geographic literacy perform better than participants with inferior cartographic and geographic literacy.

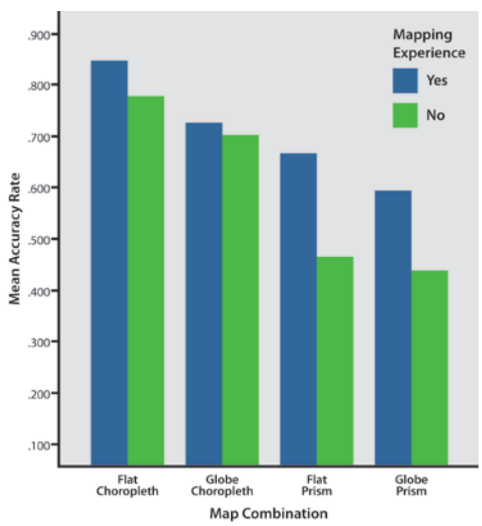

Figure 4.2b: Bar chart displaying accuracy rates by map combination grouped by mapping experience.

	Experience	n	$\bar{x}$	s	Minimum	Maximum
Choropleth	Yes	26	.722	.232	.000	1.000
	No	24	.776	.231	.200	1.000
Prism	Yes	26	.604	.241	.167	1.000
	No	24	.460	.214	.200	.800

** $p < .0125$

Table 4.2c: Mean accuracy rates separated by symbolization method and mapping experience.

4.2.3 Patience, Volunteer Status, and Overall Accuracy

After testing commenced, a new participant behavior, patience, was identified and recorded for further analysis. Participants who exhibited controlled and deliberate behavior throughout the experiment, such as reading and re-reading instructions or double-checking answers, were identified as "patient." Conversely, participants who exhibited rushed behavior and outward displays of frustration or annoyance with some aspect of the experiment (map, software, questions, etc.) were defined as "impatient." Out of the fifty participants, eleven exhibited impatient behavior, six exhibited patient behavior, and the remaining participants did not exhibit noticeable signs of either. This behavior was recorded as the variable "Patience," of which there were three categories: patient, impatient, and uncertain (neither patient nor impatient behavior observed). It was hypothesized that patient participants would answer more questions correctly than impatient participants.

Participants exhibiting patience achieved a higher mean score than either of the other two groups (Table 4.2d), which suggested that patience and accuracy rates are not independent of one another, and that "patient" participants performed better overall. A review of the corresponding distributions (Figure 4.2c) supported this assessment, as the "patient" group distributions was negatively skewed (caused by four of the six participants achieved an accuracy rate of .900), the "impatient" group distribution displayed a mild positive skew (caused by the large proportion of lower accuracy rates), and the "uncertain" group distribution was clustered around a lower mean (affected by a few outliers).

	n	$\bar{x}$	s	Minimum	Maximum	Shapiro-Wilk sig.
Impatient	11	.664	.157	.500	.900	.062
Patient	6	.800	.155	.600	.900	.001
Uncertain	33	.618	.151	.100	.900	.003

Table 4.2d: Mean accuracy rates of participants grouped by observed patience.

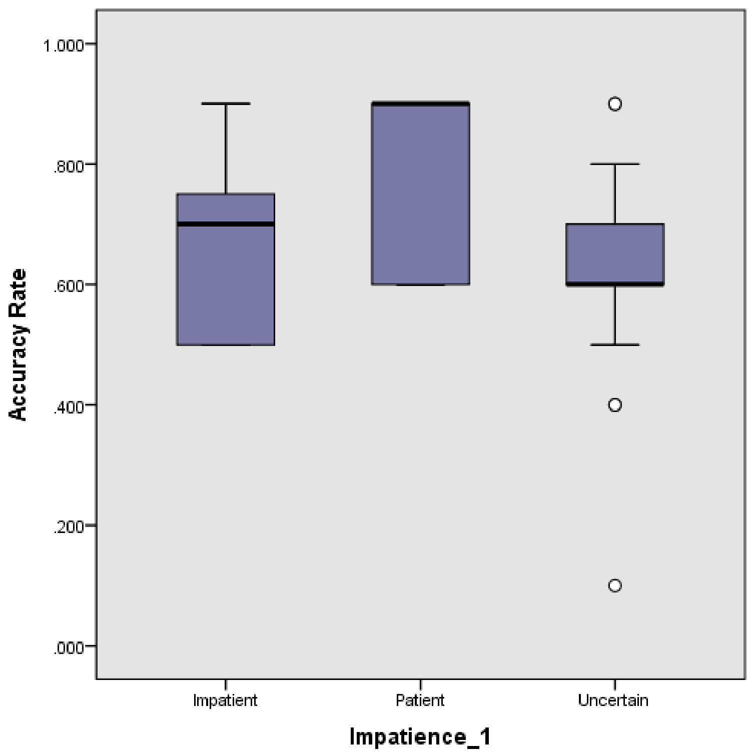

Figure 4.2c: Boxplot of participant accuracy rates grouped by observed patience.

A one-way ANOVA examining the relationship between patience and overall accuracy rates indicated a statistically significant relationship between patience and accuracy; $F(2, 47) = 3.660$, $p = .033$, partial $\eta^2 = .135$; post hoc tests using the Bonferroni adjusted comparisons, however, revealed that the only significant between-groups difference was "patient" and "uncertain" (mean difference = .182, standard error = .068). These results did not support the hypothesis that patient participants answer more questions correctly than impatient participants. Due to the small, unevenly proportioned group sizes, and also to the probability that the "uncertain" group contained both patient and impatient participants, a Mann Whitney U test was conducted to evaluate the median accuracy rates of the "patient" and "impatient" participant groups. The results of the test were in the expected direction but not significant, $z = -1.663$, $p = .096$; impatient participants had an average rank of 8.73, while patient participants had an average rank of 9.5, which indicated that while impatient participants did score lower than patient participants, the difference between the two groups was not significant.

An additional observation made after testing ended was that all "impatient" participants volunteered for this research in order to obtain extra credit, whereas all "patient" participants volunteered with no expectation of extra credit. This suggested a possible relationship between a participant's volunteer status and his or her correctness of response. Of the fifty participants, thirty-six volunteered to receive extra credit, and fourteen volunteered for no stated motive. This characteristic was recorded as the variable "Volunteer Status," of which there were two categories: extra credit and no extra credit. It was hypothesized that participants seeking extra credit would not answer as many questions correctly as those not seeking extra credit.

A basic comparison of the two groups (Table 4.2e) suggests that participants not seeking extra credit achieved higher accuracy rates than those who were seeking extra credit. A review of the histograms of each group supported this suggestion, as the extra credit group accuracy rates are more widely distributed with lower mean, median, and modal values; however, the apparent differences between these two groups may not have been significant due to the imbalanced group sizes. Due to the proportional difference between groups, and the small sizes of each, a Mann-Whitney U test was conducted to evaluate the hypothesis that participants seeking extra credit would perform worse than participants not seeking extra credit. The results of the test were in the expected direction and significant, $z = -2.069$, $p < .05$; participants seeking extra credit had an average rank of 22.4, while those not seeking extra credit had an average rank of 31.5. These results supported the hypothesis that volunteer status is an indicator of user performance.

	n	$\bar{x}$	s	Minimum	Maximum	Shapiro-Wilk sig.
No Extra Credit	14	.729	.144	.500	.900	.096
Extra Credit	35	.634	.133	.400	.900	.006

Table 4.2e: Mean accuracy rates of participants grouped by volunteer status

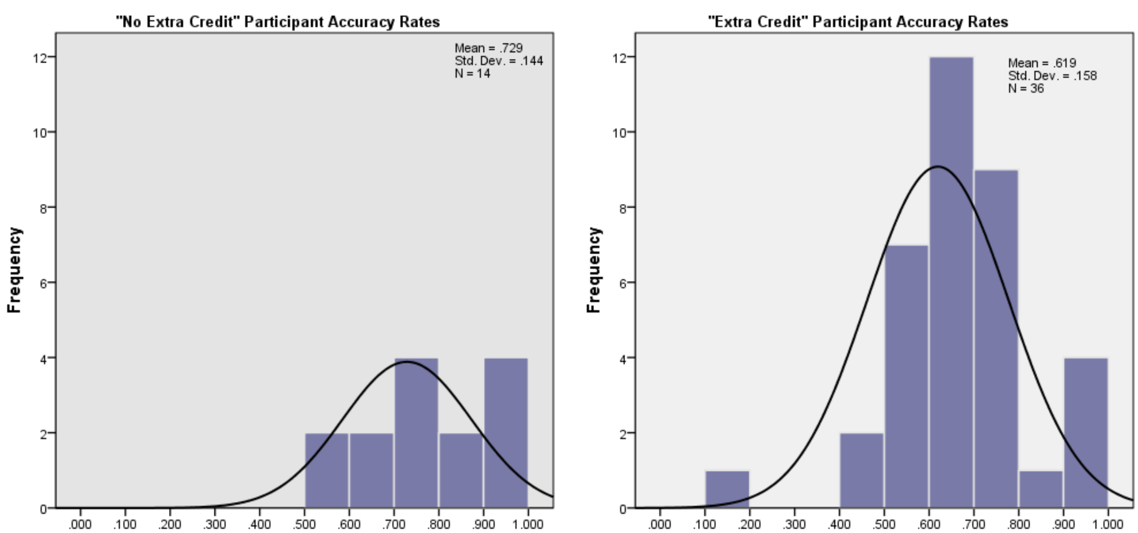

Figure 4.2d: Accuracy rate distributions of participants grouped by volunteer status

4.3 Task Completion Time

Hypothesis three of this research predicts that participant's completion times will increase as map complexity (primarily, dimensionality) increases. Completion times were gathered for every task completed during the experiment; this section examines these data to determine if any significant relationships exist with the map variables, user performance, or participant demographics. Units of time are in seconds for all statistical tests.

4.3.1 Overall Test Completion Times

The mean total test completion time (Table xx) for all participants was approximately seventeen minutes, forty seconds); however, the distribution of values tested non-normal due to the presence of two high outliers; after their removal the new distribution of values (Figure xx) tested normal around an average test time of seventeen minutes. The adjusted dataset was used for the duration of the total test time analyses.

	n	$\bar{x}$	s	Minimum	Maximum	Shapiro-Wilk sig.
Original Test Times	52	1060.12	330.64	521	2101	.001
Adjusted Test Times	50	1019.94	266.68	521	1607	.068

Table 4.3a: Descriptive statistics of original and adjusted total test completion times.

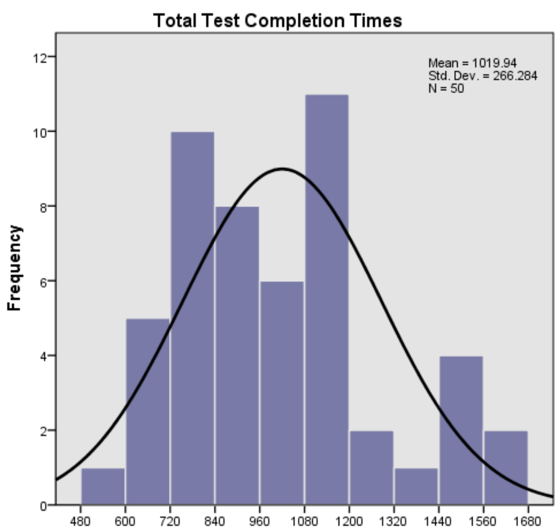

Figure 4.3a: Histogram displaying the adjusted total test completion times.

4.3.2 Completion Times and Dimensionality

The mean completion times using each of the four map variables were examined under the expectation that dimensionality would be an indicator of time. The mean completion times for each of the four map combinations (Table 4.3b) suggested that participants spent about one minute less using the choroplethic maps than they did using the prismatic maps. The distribution of completion times by map variable combination (Figure 4.3b) supports this suggestion, also showing that three map combination distributions (flat-choropleth, flat-prism, and VG-choropleth) were positively skewed, which indicated that most participants completed the test questions pertaining to each map in a relatively short amount of time. Additionally, the two prismatic maps were the only two to contain multiple outliers (these outliers were not omitted from successive analyses).

Map Combination	*n*	$\bar{x}$	*s*	Minimum	Maximum	Shapiro-Wilk sig.
Flat – Choropleth	49	213.49	60.388	94	361	.168
Flat – Prism	49	282.06	108.350	116	649	.000
Globe – Choropleth	49	229.10	57.406	103	343	.119
Globe – Prism	49	286.22	100.596	143	598	.000

$^{**}p < .0125$

Table 4.3b: Descriptive statistics of completion times by map variable combination.

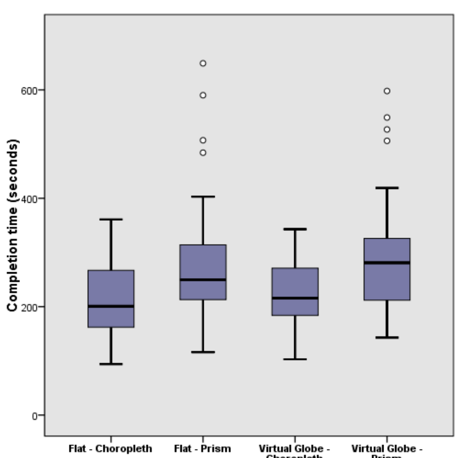

Figure 4.3b: Completion time by map combination boxplot.

A repeated measures ANOVA test was conducted to compare the effect of dimensionality on completion time. The Within-Subjects Effects test results indicated a significant interaction effect between map medium and symbolization method on time, $F(1, 49) = 14.456$, $p < .000$, partial $\eta^2 = .228$, and a significant main effect for symbolization method on time, $F(1, 49) = 47.002$, $p < .000$, partial $\eta^2 = .490$; no significant main effect was indicated for map medium, $F(1, 49) = 1.000$, $p = .322$, partial $\eta^2 = .020$. Note the magnitude of the symbolization effect size, which implied that symbolization method accounted for 49% of the overall variance within the sample (this effect size is similar to that of symbolization method on overall accuracy rates) . Bonferroni comparisons of factor interactions (Table 4.3c) between map combinations confirmed that the mean completion times of choroplethic maps were significantly lower than the mean completion times of prismatic maps.

Comparisons	Mean Accuracy Rate Difference	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Flat – Choropleth vs. Flat – Prism	-68.571**	15.088	-110.095	-27.048
Flat – Choropleth vs. Globe – Prism	-72.735**	11.184	-103.512	-41.957
Globe – Choropleth vs. Flat – Prism	-52.959**	14.416	-92.634	-13.285
Globe – Choropleth vs. Globe – Prism	-57.122**	11.184	-87.743	-26.502

** $p < 0.05$

Table 4.3c: Bonferroni comparison for completion time separated by map combination.

These results also indicate that symbol dimensionality is a predictor of participant completion time: participants take less time to answer questions using maps with 2-D choropleth symbolization and more time using maps with 3-D prism symbolization. Additionally, the results also indicate the dimensionality of the map medium does not affect participant completion times (Figure 4.3c).

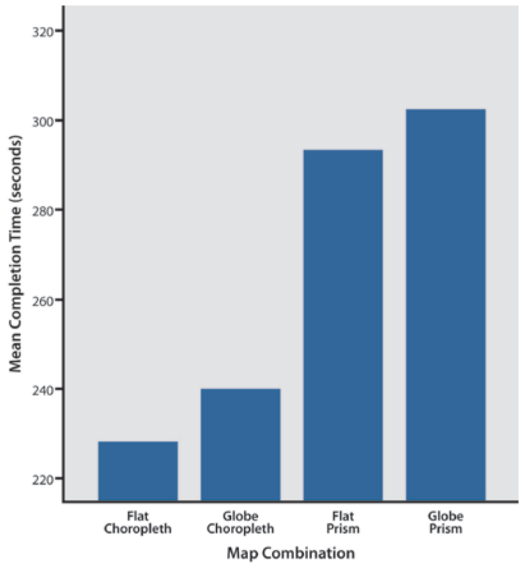

Figure 4.3c: Mean participant completion time per map combination.

4.3.3 Completion Time and Accuracy Rates

Although no hypothesis was developed to predict the relationship between a participant's completion time and overall accuracy rate, this relationship was examined for any significant correlation. A Pearson correlation coefficient was computed to assess the relationship between total completion time and accuracy rate, which revealed a small but insignificant positive correlation between the two variables ($r = .246$, $p = .085$, $n = 50$). This indicated that no significant relationship existed between a participant's overall accuracy rate and test completion time.

Further, as sections 4.1 and 4.2 revealed that dimensionality, particularly symbolization dimensionality, has a significant effect on both accuracy rates and completion times, the relationship among all three was examined for significant effects. Pearson correlation coefficients were computed to assess the relationship between completion time and accuracy rate for each map variable (e.g., choropleth completion time vs. choropleth accuracy rate); however, the magnitude and direction of all relationships were not statistically significant, indicating that dimensionality did not significantly affect the relationship between time and accuracy.

4.3.4 Exploration Times and Memory Accuracy

Prior to closing the map window and completing a memory task, participants were instructed to spend one minute "exploring" a specified region on the map relating to the memory-based questions (e.g., North America). It was predicted that those participants who spent more time exploring a map would achieve higher accuracy rates on memory-based questions.

A Pearson correlation coefficient was computed to assess the relationship between memory-based accuracy rates and total exploration time, using the full participant group. Overall, there was a significant, if moderate, positive correlation between memory-based accuracy rates and exploration times ($r = .290$, $p < .05$, $n = 52$), indicating that higher accuracy rates correspond to higher amounts of exploration time. A scatterplot summarizes these results (Figure 4.3d).

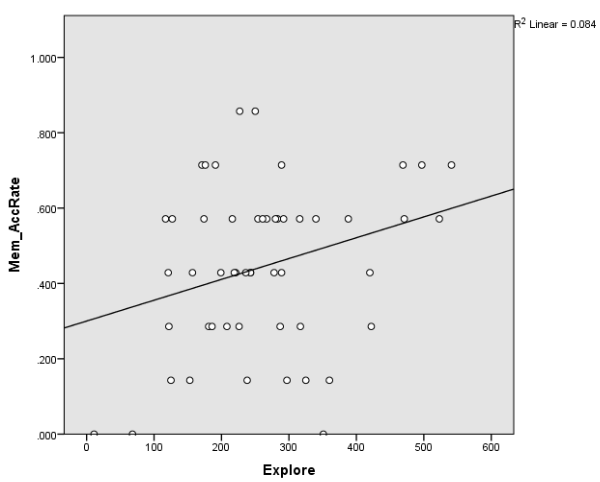

Figure 4.3d: Memory-based accuracy rate and exploration time scatterplot.

4.3.5 Test Completion Times and Participant Demographics

In addition to examining the relationships among completion times and map variables, completion times were also examined to identify potential relationships with the collected participant demographic data. In particular, the six variables identified in section 4.2.1 (major of study, cartographic course enrollment, previous mapping experience, geographic literacy, cartographic literacy, and English literacy) were used to separate the completion times of participants into comparable groups. Six separate one-way ANOVA tests were conducted to determine if any significant relationships exist between overall completion times and any of these participant characteristics; the results of each analysis, however, failed to indicate any significant relationships.

Section 4.2.4 also describes how a participant's observed patient or impatient behavior was hypothesized to be related to correctness of response; this behavior was also predicted to affect test completion times. The results of a one-way ANOVA examining this relationship failed to indicate a significant relationship; $F(2, 49) = .428$, $p = .654$, partial $\eta^2 = .017$. As an extension of this assessment, the potential relationship between a participant's volunteer status and test completion time was also examined. The mean test times between volunteers ($\bar{x} = 928.64$, $SD = 258.87$, $n = 14$) and those seeking extra credit ($\bar{x} = 1108.55$, $SD = 343.79$, $n = 38$) appeared different, but an independent samples t-test did not indicate a significant relationship between the two variables; $t(48) = 3.157$, $p = .56$. It should be noted, however, that the p-value does approach the overall level of significance (.05).

4.4 User Preference Results

A post-test questionnaire consisting of nine questions (Appendix D) was the final task of the experiment. Participants responded to a series of multiple choice, Likert-scale, and ordinal questions regarding their preference for and perceived effectiveness of each map variable and map variable combination (e.g., "Which symbolization method do you prefer?" "Rate the effectiveness of each symbolization method at displaying data values"). This section tests hypothesis four, which posits that user preference for a particular map variable combination will increase as the map's dimensionality, dynamism, and interactivity increase. In addition, participant data were examined for evidence of naive cartography, wherein preference is shown for increased dimensionality, dynamism, and interactivity even if performance suffers from those increases.

4.4.1 Post-Test Questionnaire Results

Overall, participants indicated a preference for 2-D map variables over 3-D map variables (Table 4.4a). Although a majority of participants preferred the flat map (53%) over the VG (13%), one-third of participants indicated no preference for either medium. Preferences for symbolization method were less ambiguous, as a strong majority (79%) selected 2-D choropleth over 3-D prisms (15%), with only 6% stating no preference for either method.

Q4: Which map medium do you prefer?	
Flat Map	53%
Virtual Globe	13%
No Preference	33%

Q5: Which symbolization method do you prefer?	
Choropleth	79%
Prism	15%
No Preference	6%

Table 4.4a: Preference for map medium (left) and symbolization method (right) by percentage of respondents (rounded to nearest whole number).

In addition to indicating map variable preferences, participants also rated the effectiveness of each map variable on a Likert scale (1 = ineffective through 5 = effective). Paired-samples t-tests were performed to compare the means of both map medium rankings and symbolization method ratings, and the results indicated participants rated flat maps effectiveness ($\bar{x}$ = 3.73, s = .694) significantly higher than VG effectiveness ($\bar{x}$ = 3.40, s = .647), $t(49) = 2.657$, $p < .05$; and choroplethic symbolization effectiveness ($\bar{x}$ = 4.14, s = .700) was ranked significantly higher than prismatic symbolization effectiveness $\bar{x}$ = 2.98, s = 1.059), $t(49) = 6.096$, $p < .05$.

Preferences for individual map variables carried over to preferences for each of the four map combinations (Table 4.4b). Participants were instructed to rank their preference for each combination (1 = highest preference through 4 = lowest preference), and the first choice was the choroplethic flat map, followed in order by the choroplethic VG, the prismatic VG, and the prismatic flat map. Overall, 58% ranked both choropleth maps over both prism maps, whereas just 4% ranked both prism maps over both choropleth maps.

Preference Ranking	Flat Map – Choropleth	Virtual Globe – Choropleth	Flat Map – Prism	Virtual Globe – Prism
1	54%	26%	4%	16%
2	34%	40%	16%	10%
3	10%	20%	46%	24%
4	2%	14%	34%	50%

Table 4.4b: Preference rankings for each map combination by percentage of respondents (rounded to nearest whole number).

Participants also assigned Likert ratings to all four map combinations. These ratings produced slightly different results from the combination preference rankings (Table 4.4c). The distribution of effectiveness ratings for each combination (Figure 4.4a) shows a noticeable difference between the perceived effectiveness of the flat – choropleth map (the sharp negative skew conforms to the high mean score) and the other three maps (less skew, kurtosis, and lower means and modes).

Effectiveness Rating	Map Variable Combination	$\bar{x}$	s
1	Flat map – Choropleth	4.06	1.038
2	Virtual Globe – Prism	3.56	1.163
3	Virtual Globe – Choropleth	3.40	1.010
4	Flat map – Prism	3.24	1.135

Table 4.4c: Map variable combination effectiveness ratings.

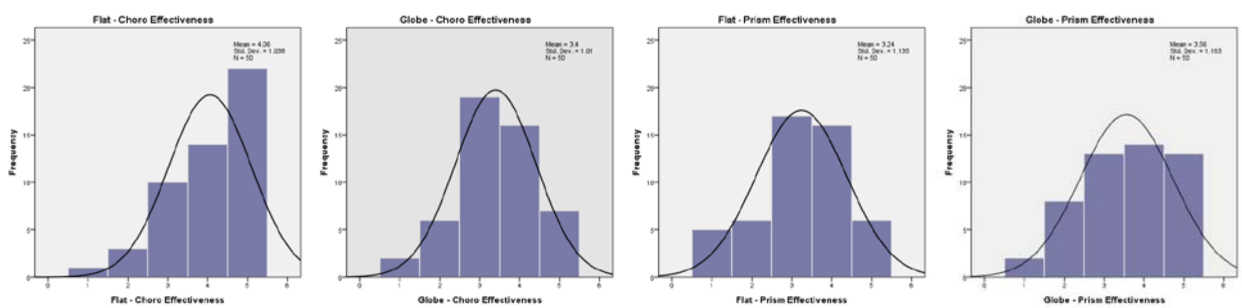

Figure 4.4a: Histograms of map variable combination effectiveness rankings.

A repeated measures ANOVA was conducted to compare each of the four map combination effectiveness ratings. The Within-Subjects Effects test results indicated a statistically significant difference between one or more of the ratings, $F(2.570, 181.855) = 5.091$, $p < .05$, partial $\eta^2 = .094$. Post hoc tests using the Bonferroni adjusted comparisons of factor interactions revealed that participants rated choroplethic flat map effectiveness significantly higher than choroplethic VG effectiveness (mean difference = .660) and prismatic flat map effectiveness (mean difference = .820).

4.4.2 Map Variable Preference and Demographics

Chi-Square tests of independence were performed to examine the relationship between map variable preferences and each of the six participant demographic data discussed in section 4.2.1. Since none of the tests indicated the presence of significant differences between participant groups and map preferences, map variable and map combination preferences appear to remain the same regardless of a participant's geographic, cartographic, or graphic literacy skills.

4.4.3 Map Variable Preference and Performance

According to the naïve cartography concept, which suggests map users tend to prefer complex displays regardless of how those displays effect performance, it was expected that participants who indicated a preference for 3D map variables would have lower accuracy rates than participants who preferred 2D map variables. The mean accuracy rates using preferred map combinations (Table 4.4d) suggested that those who preferred choroplethic flat maps performed more accurately using that map combination than all other participants, particularly those who preferred prismatic VGs or flat maps (mean differences = .182). The results of a one-way ANOVA test, however, indicated no significant difference of the mean accuracy rates among the groups, $F(3, 46) = 1.136$, $p = .344$, partial $\eta^2 = .069$. It was concluded that individual mean accuracy rates using a particular map combination was not related to a preference for that combination.

Preferred Map Combination	$\bar{x}$	s	n
Flat map – Choropleth	.765	.282	27
Virtual globe – Choropleth	.667	.245	13
Virtual globe – Prism	.583	.333	8
Flat map – Prism	.583	.118	2

Table 4.4d: Mean accuracy rates for preferred map combinations.

An examination of symbolization method preference by mean accuracy rates suggested a difference between those who prefer choropleth maps and those who prefer prisms. Participants who indicated a preference for choropleth achieved higher accuracy rates ($\bar{x}$ = .735, s = .249, n = 40) than those who preferred prisms ($\bar{x}$ = .407, s = .171, n = 10). The results of an independent samples t-test indicated that the mean accuracy rates of each group were significantly different, $t(48) = 3.933$, $p < .000$. This result suggested that, in regards to symbolization method preference, the accuracy rates of participants who preferred 3-D were significantly lower than the accuracy rates of participants who preferred 2-D. A similar independent samples t-test examining the same relationship for map medium indicated no significant difference between groups, such that individual mean accuracy rates using a particular map medium was not related to a preference for that map medium.

Additionally, it was expected that the mean accuracy rates of participants using a preferred map variable or combination would differ from the mean accuracy rates of participants using (but not preferring) that particular map variable or combination; however, a series of independent samples t-tests examining these relationship indicated no significant differences existed between the mean accuracy rates of these groups.

4.4.4 Map Variable Preference and Completion Times

It was expected that map variable preferences would be influenced by the time spent answering questions using maps containing those variables, such that a relationship would exist between preference and map completion time (although the strength and direction of these possible relationships was not speculated on).

The mean completion times using preferred map combination preferences (Table 4.4e and Figure 4.4b) suggests those who selected the prismatic VG spent considerably more time using that map combination than all others. The results of a one-way ANOVA indicated a statistically significant difference between one or more of the mean completion times, $F(3, 46) = 9.314$, $p < .05$, partial $\eta^2 = .378$. Post hoc comparisons using Bonferroni corrections revealed two significant differences, between prismatic VGs and both choroplethic VGs (mean difference = 155.49 seconds) and choroplethic flat maps (173.62 seconds). These results supported the suggestion that the completion times of those who preferred the prismatic VG were higher than all others, and significantly higher than both choropleth maps.

Preferred Map Combination	Preferred $\bar{x}$	s	n	Overall $\bar{x}$
Flat map – Choropleth	210.26	68.580	27	213.49
Flat map – Prism	299.50	146.371	2	282.06
Virtual globe – Choropleth	228.38	43.210	13	229.10
Virtual globe – Prism	383.88	149.796	8	286.22

Table 4.4e: Mean completion times for preferred map combination compared to overall mean completion times of each map combination.

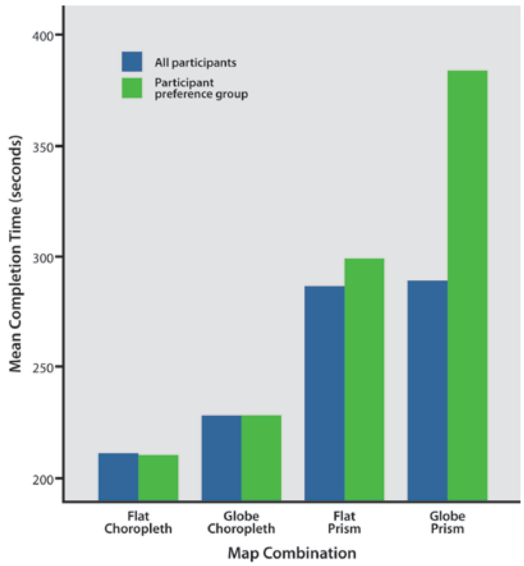

Figure 4.4b: Mean completion time by preferred map combination.

The mean completion times obtained using preferred map media showed that participants who preferred flat maps ($\bar{x}$ = 245.6, *s* = 71.9, *n* = 29) took noticeably less time per map (mean difference = 51.3 seconds) than those who preferred VGs ($\bar{x}$ = 297.0, *s* = 99.4, *n* = 21). The results of an independent samples t-test indicated a statistically significant difference between the two groups, $t(48) = -2.12$, $p < .05$. It was concluded that participants who indicated a preference for flat maps spent significantly less time using them than those who preferred VGs.

An examination of mean completion times by symbol preference produced similar results. Participants who indicated a preference for choroplethic maps ($\bar{x}$ = 222.8, *s* = 52.7, *n* = 40) took considerably less time per map (mean difference = 129.7 seconds) than those who preferred prismatic maps ($\bar{x}$ = 352.5, *s* = 129.5, *n* = 10). The results of an independent samples t-test indicated a statistically significant difference between the two groups, $t(48) = -3.10$, $p < .05$. Participants who indicated a preference for choroplethic maps spent significantly less time using choroplethic maps, and those who preferred prismatic maps spent more time using prismatic maps.

4.4.5 Map Variable Preference and Assumed Effectiveness

Map variable preferences were also examined for potentially significant relationships with map variable effectiveness ratings. The expectation was that participants who expressed a preference for one map variable or map variable combination would also assign that variable or combination a higher effectiveness rating.

A review of the mean effectiveness ratings assigned by each of the four preferred map combinations (Table 4.4f) suggested that a participant's preference for a particular map combination may not match his or her measure of that combination. A repeated measures ANOVA was conducted to compare map combination preference and effectiveness ratings. The Within-Subjects Effects test results indicated a statistically significant interaction between the two factors, $F(9, 138) = 5.328$, $p < .05$, partial $\eta^2 = .258$. These results indicate that participants assigned the highest effectiveness rating to their preferred map combination, and that these ratings were significantly higher than the ratings assigned to the other map combinations (participants who preferred choroplethic VGs were the only group who did not rate their preferred map combination highest; they rated prismatic VGs higher). (Figure 4.4c).

Preferred Map Combination	$\bar{x}$	s	n
Flat map – Choropleth	4.44	.801	27
Virtual globe – Choropleth	3.69	1.032	13
Flat map – Prism	4.50	.707	2
Virtual globe – Prism	4.50	.756	8

Table 4.4f: Mean effectiveness ratings given to preferred map combination.

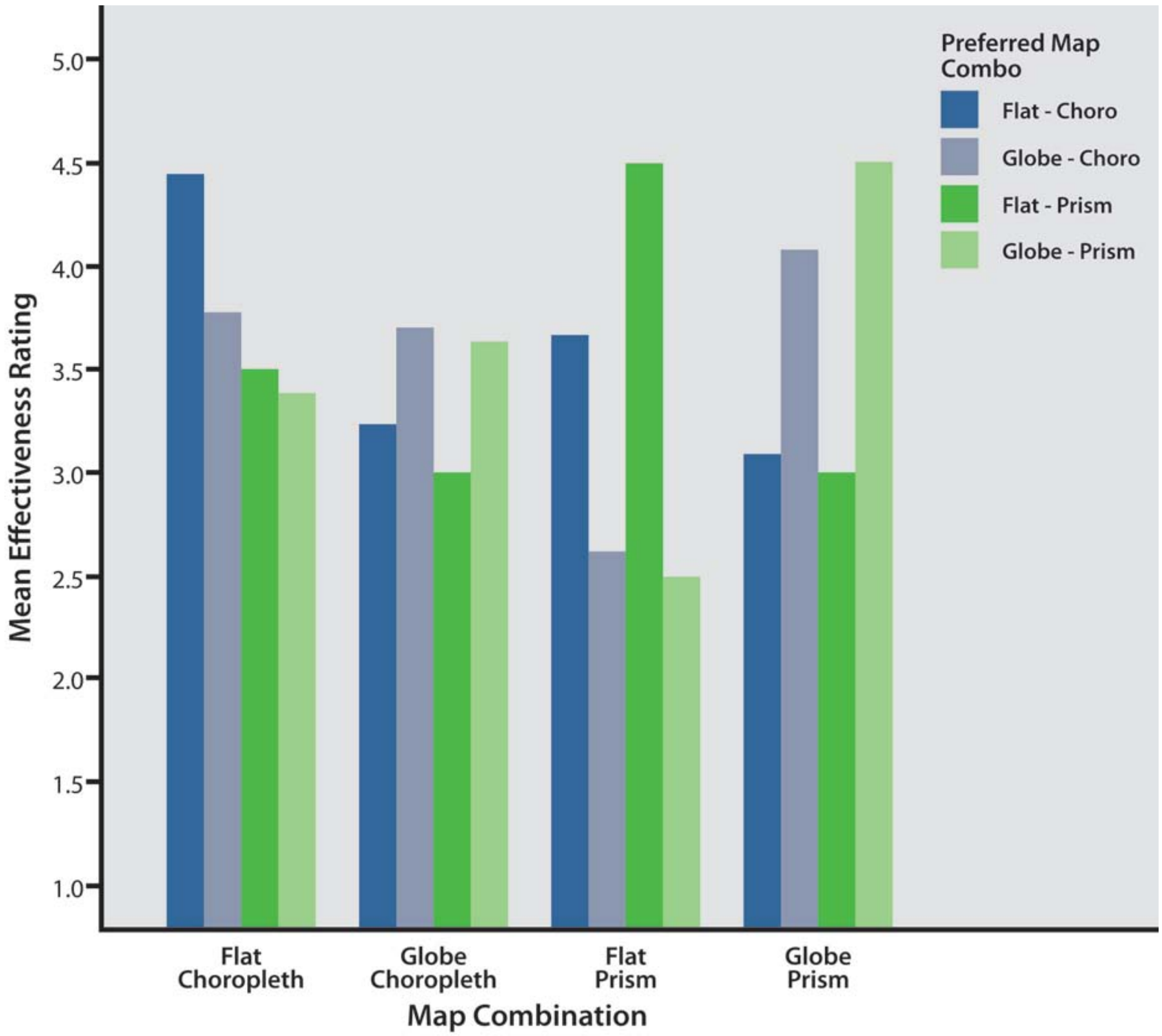

Figure 4.4c: Mean effectiveness ratings of map combinations separated by preferred map combination.

Two additional repeated measures ANOVA tests were conducted to examine individual map variable preferences and effectiveness ratings, one evaluating the relationship between map medium preferences and map medium effectiveness ratings, the other evaluating the relationship between symbolization method preference and effectiveness. The Within-Subjects Effects results of the map medium test did not indicate a significant interaction between the medium preference and effectiveness rating, $F(1, 48) = .391$, $p = .534$, partial $\eta^2 = .008$.

Participants who stated a preference for choropleth assigned higher effectiveness ratings to choroplethic maps, and those who preferred prisms also assigned higher effectiveness rating to choroplethic maps (Table 4.4g). Note that regardless of preference, when evaluating symbol effectiveness participants rated 2-D variables higher than 3-D variables. The Within-Subjects Effects results of the symbolization method test indicated a significant interaction between the preference and effectiveness, $F(1, 48) = 7.163$, $p < .05$, partial $\eta^2 = .130$; these results also indicated a significant difference of the effectiveness ratings between the two preference groups, and within the choropleth preference. A post hoc independent samples t-test indicated that participants who preferred prisms assigned significantly higher effectiveness ratings to prisms than did participants preferring choropleths, $t(48) = -2.144$, $p < .05$. A post hoc paired samples t-test indicated that, within the choropleth preference group, choropleth effectiveness ratings were significantly higher than prism effectiveness ratings, $t(39) = 3.027$, $p < .05$; the effectiveness ratings within the group of participants who preferred prisms were not significantly different (Figure 4.4d).

Symbol Preference	Symbol Effectiveness	$\bar{x}$	s	n
Choropleth	Choropleth	4.22	.698	40
	Prism	2.82	.984	40
Prism	Choropleth	3.80	.632	10
	Prism	3.60	1.174	10

Table 4.4g: Mean symbolization method effectiveness ratings separated by symbol preference.

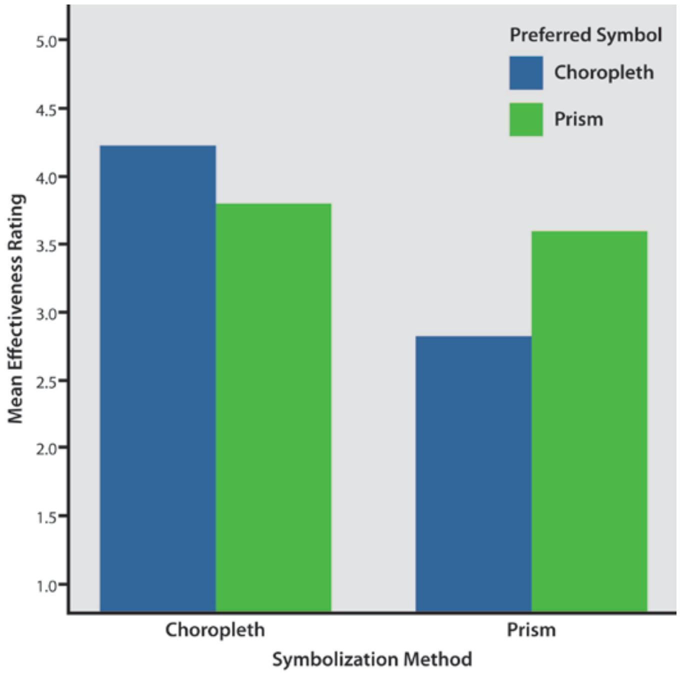

Figure 4.4d: Mean effectiveness ratings of symbolization method separated by preferred symbol.

CHAPTER 5: DISCUSSION

5.1 Summary of Findings

The map comparison experiment and results described in chapters three and four are intended to build upon previous cartographic research evaluating the thematic mapping potential of VG environments. The parameters of this experiment are narrow enough to have limited applicability to existing conventional cartographic design guidelines, but the findings do provide insight into the overall effectiveness of VGs as a mapping medium. Particularly, there was a discernible pattern of the effect of dimensionality on the outcomes of each hypothesis test.

The experiment confirmed hypotheses one through three: 1) map dimensionality, dynamism, and interactivity (display complexity) increases did cause user performance levels to decrease; 2) user performance was also influenced by map reading skill level, as participants who possessed superior map reading skills performed better across all maps than those with inferior skills; and 3) display complexity increases did cause task completion times to increase. The fourth hypothesis, which predicted that map preferences and judgments of map effectiveness would be influenced by the principles of naïve cartography, is only partially confirmed, as some participants exhibited naïve cartography characteristics and others did not. Each of these hypotheses and the relevant findings confirming or opposing each are discussed in the sections below.

5.2 User Performance

5.2.1 User Performance and Dimensionality

User performance results confirm the prediction of hypothesis one, showing that user performance worsens as map dimensionality, and by extension interactivity and dynamism, increase. Within the scope of this experiment, the most noteworthy aspect of all user performance analyses is the consistency of dimensionality effects on accuracy rates.

When the dimensionality of the map variables is factored in, by main effects and through interaction, three patterns emerge. First, map medium dimensionality has little impact on user performance; changing the medium from a flat map to the VG causes accuracy rates to drop insignificantly, although the drop is measureable (generally ten percentage points or less which, to use a classroom analogy, represents up to one full letter grade). Second, symbolization dimensionality has a significant impact on user performance; changing symbols from choropleths to prisms causes accuracy rates to plummet (generally between fifteen and thirty percentage points). Third, when the two map variables interact, participants perform best using map combinations with low display complexity (choroplethic flat maps) and worst using map combinations with high display complexity (prismatic VGs).

These findings suggest that, within this experiment, and as it pertains to user performance, the choroplethic flat map was the most effective of all four map combinations (Table 5.2a). The more significant finding is that symbolization method selection, *not* map medium, is the stronger indicator of success. It was the use of 3D symbolization within either map medium that exacerbated the scale, location, depth, and occlusion problems inherent to 3D environments and depressed accuracy rates. In fact, using a 3D environment (VGs) to display 2D symbolization (choropleths) results in significantly better user performance than using a 2D environment (flat maps) to display 3D symbolization (prisms). These findings suggest VGs are potentially suitable environments for thematic mapping, provided they are paired with an appropriate symbolization method.

Map combination	Mean Accuracy Rate	Mean difference (from Flat-Choro)	% change
Flat map – Choropleth	.813	—	—
Virtual globe – Choropleth	.713	– .100	– 12.3%
Flat map – Prism	.567	– .246	– 30.3%
Virtual globe – Prism	.507	– .306	– 37.6%

Table 5.2a: Accuracy rate decreases caused by dimensionality increases.

A VG requires a minimum amount of interaction and dynamism to display the Earth's entire surface, as a majority of the globe is not visible in any one view. Constant rotation and adjustment is required to explore and understand data; understandably, accuracy rates decreased as participants had to account for this added display complexity, although not significantly. The absence of significant accuracy rate differences between flat maps and VGs is unexpected. A possible explanation for this occurrence is that, as suggested by Goodchild's (2008), all participants possess an inherent mental image of the Earth's physical appearance similar to the appearance of the VG. Additionally, most participants likely are familiar with the basic VG user interface common to many other non-map applications. Taken together, these suggest the representation of the earth as a VG compared to a flat map is not significantly more difficult to comprehend or use.

Conversely, symbolization can change the appearance of either representation of the Earth so that its physical appearance (e.g., the shape of the continents or country borders) is no longer recognizable, complicating map exploration and reading activities. Choropleths are unobtrusive objects, remaining flat upon the surface and retaining the shapes of all enumeration units (countries); their preservation of the Earth's general appearance (with the obvious exception of the color values) supports, or at least does not get in the way of, navigation and map exploration and reading tasks. Prisms, in comparison, are unnatural and obtrusive. Although their surfaces retain the shape of each enumeration unit, depending on the range of prism height values within the dataset, prisms can obscure much of the earth's surface from any single perspective, and often one another. As a result, the representation of the earth is less familiar, less inherently understood, and so map reading activities become much more involved, more demanding, and less natural. Reader focus shifts from the content of the data to the appearance of the data.

5.2.2 Demographics, Performance, and Dimensionality

Grouping user performance data by particular demographics confirmed the prediction of hypothesis three, that participants possessing superior map reading skills perform better than participants with inferior map reading skills.

The pre-test literacy assessments identified participants with deficient geographic literacy skills, and those participants performed poorly across all map variables and combinations regardless of display complexity. This indication is obvious enough: participants lacking geographic literacy do not perform well on map tasks. One demographic variable, mapping experience, was identified as a useful proxy that accounted for a participant's cartographic, geographic, and graphic literacy skills. As a group, participants indicating prior mapping experience were geography majors, had completed or were enrolled in a cartography course, and collectively scored better on all three pre-test literacy assessments than did the participants without mapping experience.

Within this research, participant mapping experience is a significant indicator of overall performance. The pattern of decreased accuracy rates caused by increased dimensionality remained the same regardless of grouping by mapping experience, but the magnitude of accuracy rate deterioration between the two groups was remarkable (Tables 5.2b and 5.2c). These results show that, while the accuracy rates of both groups decreased with each dimensionality change (particularly with the change from choropleth to prism), the decrease was considerably steeper for the non-mapping experience group. These differences in group performance were not unexpected, as participants familiar with both reading and making maps were better prepared to use the experiment maps to correctly answer the test questions; however, these results also indicate that increasing display complexity adversely affected *all* participants.

Map combination	Accuracy rate (Mapping exp.)	Accuracy rate (NO mapping exp.)	Mean difference	% change
Flat map – Choropleth	.847	.778	– .069	– 8.2%
Virtual globe – Choropleth	.727	.701	– .026	– 3.6%
Flat map – Prism	.667	.465	– .202	– 30.3%
Virtual globe – Prism	.593	.438	– .155	– 26.1%

Table 5.2b: Participant mean accuracy rate changes between mapping experience groups, separated by map combination.

Mapping experience	Flat map – Choropleth	Virtual globe – Choropleth	Flat map – Prism	Virtual globe – Prism
Yes	.847	.727 (– 14 %)	.667 (– 21 %)	.593 (– 30 %)
No	.778	.701 (– 10 %)	.465 (– 40 %)	.438 (– 44 %)

Table 5.2c: Participant mean accuracy rate changes among the four map combinations, grouped by mapping experience; percentage change from choroplethic flat map values.

Perhaps because choropleth maps are so prevalent in mass media, college course material, and even in video games, the mean accuracy rate differences of each group using each choroplethic map is small (to again use the classroom analogy, less than one letter grade). Although neither group performed well using prisms, the accuracy rates of participants with mapping experience were not as adversely affected by symbol dimensionality increases. But participants without prior mapping experience were especially prone to the 3D problems caused by prisms, appearing unable to successfully navigate through the map displays or understand data values represented by prism heights.

Accuracy rate deterioration caused by display complexity between both groups also reconfirms hypothesis one. Taken together, the results of both hypothesis tests indicate that poorly designed maps or poor graphical representations of geographic data caused by increased display complexity (which is caused by increased dimensionality) are not easily read or interpreted by map readers of any skill level.

5.3 Time

5.3.1 Overall Completion Times

This experiment was designed so that participants could complete all sections of the test (pre-test survey, test, and post-test questionnaire) in approximately thirty minutes. The test, composed of exploring and answering questions using the four different map combinations, was the only timed portion of the experiment. On average, participants completed the test in seventeen minutes, forty seconds, spending approximately twenty-five percent of the total time (four minutes, twenty-nine seconds) exploring the maps and the remaining seventy-five percent (thirteen minutes, twenty-three seconds) answering questions. Completion times were expected to be significantly affected in one direction or another by display complexity (dimensionality, interactivity, and dynamism), participant demographics, literacy skills, and possibly through some interaction of these factors.

5.3.2 Time and Dimensionality

Hypothesis three of this research predicted that completion times would increase as display complexity increased, or there would be a significant, direct linear relationship between time and map complexity. The reasoning for this prediction is similar to the inverse relationship between user performance and map complexity; just as increasing the dimensionality of the map medium or symbolization method should result in less effective map displays, the display complexity caused by dimensionality increases was also expected to increase the amount of time necessary to explore and extract information from a particular map.

The choroplethic flat map (2D symbol/2D medium) used in this experiment can be read using a single, orthographic perspective with a minimum of interactivity, as the user does not need to spend time changing the scale or perspective of the map to view the map's contents. The choroplethic VG (2D/3D) obscures more than half of the globe (and dataset) from any one view, so users must employ multiple perspectives to explore and read the entire map. Changing perspectives requires more interactivity, affects the dynamic characteristic of the globe, and ultimately takes more of the user's time. Due to the problems of scale, location, depth, and occlusion, the prismatic flat map (3D/2D) cannot be effectively read using a single perspective, and so demands greater interactivity, which in turn affects the dynamism of the map and again requires that a user spend more time to explore and understand the data. The prismatic VG (3D/3D) combines the challenges presented by 3D media and 3D symbolization to create a map display that requires the greatest amount of interactivity, the greatest changes to the map's dynamic character, and the most time from the user.

The results of this experiment confirmed these expectations, showing that completion times increased significantly as map dimensionality increased (Table 5.3a). Note that participants spent more than one additional minute using either of the prismatic maps than they did the choroplethic flat map, which increased the total completion time by approximately one-third.

Map combo	Mean time	Mean time difference (from Flat - Choropleth)	% increase (from Flat - Choropleth)
Flat map - Choropleth	213.5	—	—
Virtual globe - Choropleth	229.1	+ 15.6	+ 7.3 %
Flat map – Prism	282.1	+ 68.6	+ 32.1 %
Virtual globe – Prism	286.2	+ 72.7	+ 34.1 %

Table 5.3a: Completion time differences by map combination.

Although the analysis indicated a significant interaction effect between map medium and symbolization method, the magnitude of the symbolization method main effect revealed that the effect of symbol dimensionality on overall map complexity, not the effect of map medium dimensionality, is largely responsible for significant increases in completion time (Table 5.3b). Completion time differences between symbolization methods is even larger than by map combination, with participants spending an average three minutes, forty-three seconds per choropleth map and five minutes, thirteen seconds per prism map.

Map variable	2D	3D	Mean time difference	% increase
Map medium	250.0	260.0	+ 10.0	+ 4 %
Symbolization method	222.6	312.5	+ 89.9	+ 40.4 %

Table 5.3b: Completion time differences by map variable and dimensionality.

Both tables support the results of the completion time data analyses and confirm hypothesis three, that completion times *do* increase as map complexity increases. What is notable, however, is that map complexity caused by symbolization method is a stronger indicator of completion time than complexity caused by map medium. This suggests that, within this experiment, the VG environment, by itself, was not responsible for increased map reading and exploration times. Instead, the use of 3D symbolization within the 3D environment exacerbated the problems of scale, location, depth, and occlusion, and affected the time spent perusing the map display.
One additional, possibly problematic, effect of symbol dimensionality is that, as the prisms were built from each country's surface area, the resultant displays distorted the familiar shape of the earth's landmasses (Figure 5.3a). It is likely that many participants use these landmasses as a reference to navigate around each map, and the transformation of these familiar areas into unfamiliar polygons is the reason completion times increased so significantly.

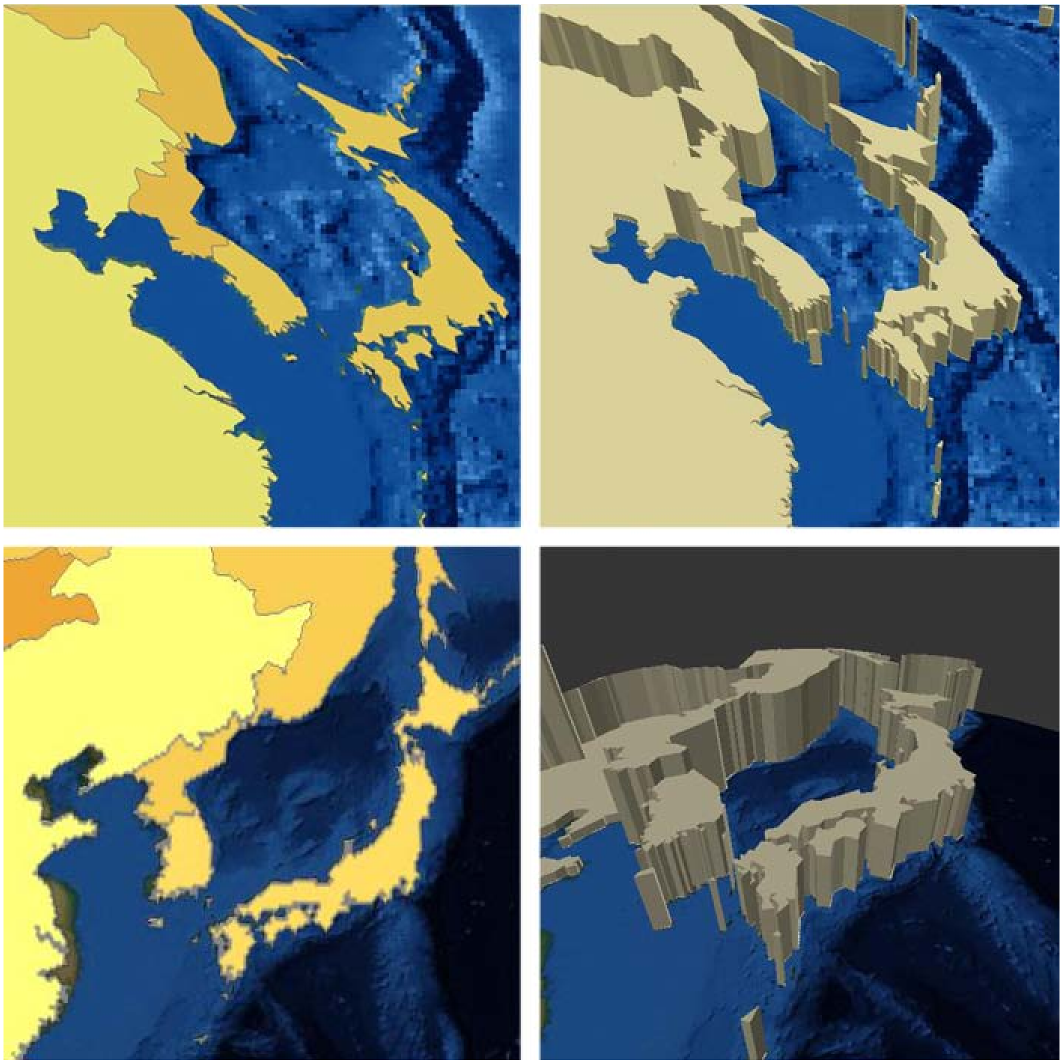

Figure 5.3a: Prisms and landmass surface distortion. Screenshots of East Asia taken from each of the four map combinations show how varying prism heights obscure recognizable surface shapes and political boundaries. Clockwise from top-left: choroplethic flat map, prismatic flat map, prismatic virtual globe, choroplethic virtual globe. © 2012 ESRI.

5.3.3 Time and User Performance

Although a relationship between time and dimensionality was predicted, no such prediction was made for user performance and time, nor was time expected to be an indicator of overall accuracy. The experiment results demonstrated that completion times by map combination, ordered shortest to longest, were similar to the results evaluating user performance. Increases in dimensionality resulted in similar changes to both completion times and accuracy rates (Table 5.3c). Regardless of this similarity, however notable, dimensionality was also not expected to explain (or be responsible for) a relationship between user performance and test times.

Map combo	Mean time	Mean time diff.	% change in time	Mean acc.	Mean acc. diff.	% change in acc.
Flat map – Choropleth	213.5	—	—	.813	—	—
Virtual globe – Choropleth	229.1	+ 15.6	+ 7.3 %	.713	- .100	– 12.3 %
Flat map – Prism	282.1	+ 68.6	+ 32.1 %	.567	- .246	– 30.3 %
Virtual globe – Prism	286.2	+ 72.7	+ 34.1 %	.507	- .306	– 37.6 %

Table 5.3c: Comparison of completion time and accuracy rate differences by map combination.

The results of the analysis examining this potential relationship, however, indicated the relationship was weak and insignificant. This result can be explained by the expected variability in participant map use behavior: some participants who achieved high accuracy rates did so in short amounts of time while others took longer, and the same is true for participants who achieved average or low accuracy rates.

5.3.4 Exploration Times and Memory Accuracy

The purpose behind assessing exploration times and memory accuracy derived from the initial observation of patient behavior versus impatient behavior. Not every participant displayed overt patience or impatience, and it was only after several participants exhibited either behavior that a pattern appeared to emerge: those who did not spend time exploring the map prior to closing the map window for the memory-based questions – per the map instructions – did not seem to correctly answer as many questions as did those participants who followed the instructions. This led to the prediction that patient participants would perform better than impatient participants.

The point of interest here is that, unsurprisingly, participants who paid attention to test instructions and spent time exploring each map in preparation for the memory-based sections of the test did, in fact, perform better than those who did not. Particularly, the results of the Pearson correlation test showed a significant, if weak-to-moderate, relationship between the two. This suggests further that while overall participants did not perform well on any of the memory-based questions, regardless of map variable combination, participants who explored could be expected to achieve a higher memory-based accuracy rate.

5.4 User Preference

5.4.1 Post-test Questionnaire Results

Given the choice between each of the two map variables, the majority of participants selected 2D over 3D. The proportions of each, however, are not equivalent: only fifty-three percent prefer flat maps to VGs (and, as stated, one-third indicated "no preference"), whereas seventy-nine percent prefer choropleth over prisms. Map variable combination preference rankings reflect these results, as participants indicated a significant preference for the map with the least amount of dimensionality, the choroplethic flat map, and by extension the characteristics of its 2D/2D environment. This resulted in the least amount of map complexity among all four map combinations. In general, though, and similar to the results of the accuracy rates and completion times analyses, map combination preference is primarily influenced by the symbolization method used in the map, not the map medium.

The effectiveness ratings demonstrate that, as with preference, participants judged the low display complexity of the choroplethic flat map the most effective map combination in the experiment. This shows that, across the test and post-test questionnaire, the choroplethic flat map was assumed to be more effective than all other map combinations, was the most preferred of the four combinations, and was used to achieve the highest accuracy rates and the shortest completion times (Table 5.4a).

	Mean Effectiveness	Preferred Map Combination	Mean Accuracy Rate	Mean Completion Time
1.	Flat – Choropleth	Flat – Choropleth	Flat – Choropleth	Flat – Choropleth
2.	VG – Prism	VG – Choropleth	VG – Choropleth	VG – Choropleth
3.	VG – Choropleth	VG – Prism	Flat – Prism	Flat – Prism
4.	Flat – Prism	Flat – Prism	VG – Prism	VG – Prism

Table 5.4a: Map combinations ordered by test results. Effectiveness, preference, and accuracy, highest to lowest; completion time, shortest to longest.

These preference and effectiveness responses generally refute the naïve cartography prediction set forth by hypothesis four, that user preference for a particular map will increase as its display complexity increases. The notable exception supporting this prediction is the high effectiveness rating given to prismatic VGs, the map combination containing the highest display complexity. Whether because participants thought the 3D/3D variable combination was 'better,' or easier to use, or perhaps more aesthetically pleasing than the 2D/3D variable combinations, this result suggests participants are exhibiting some symptoms of naïve cartography.

The interaction of preferences and effectiveness ratings reveals a lack of overall consistency among the participants. Unlike the other preference groups, those who indicated a preference for choroplethic VGs did not also rate this combination's effectiveness higher than all other map combinations (this group rated choroplethic flat maps and prismatic globes higher). Additionally, while some participants indicated a preference for prisms, both symbol preference groups assigned a higher mean rating to choropleths than to prisms (recall there was no significant interaction between map medium preference and effectiveness rating). Also notable is the polarizing effect of prisms on effectiveness ratings; whereas the choroplethic map effectiveness ratings are generally clustered at similar values, prismatic map effectiveness ratings are highly varied. This suggests that most participants agree on the effectiveness of choropleths, but not prisms. Participants who prefer low display complexity (choroplethic flat map) are strong in their conviction that this variable and map combination is more effective and "better" than the alternatives. Participants who prefer more display complexity also exhibit more ambiguity as to which symbol, map medium, or combination is more or less effective; effectiveness ratings based on these preferences are less predictable. These interactions further support the existence of naïve cartography among the participants, as an *absence* of cartographic naïveté would result in consistent effectiveness ratings (2D/2D = highest, 3D/3D = lowest), and no participants would indicate a preference for either prismatic map.

5.4.2 Preference and User Performance

Another facet of naïve cartography is that map users will show a preference for complex map displays regardless of the effects that complexity has on their performance. The significance of the user performance data, when sorted by map variable preference, supports this notion. Instead of finding little or no difference in the accuracy rates between all groups, four-fifths of participants who preferred choropleths achieved a mean .735 accuracy rate using choroplethic maps, whereas the remaining one-fifth who preferred prisms scored a significantly lower mean .407 accuracy rate using prismatic maps. That participants overall scored poorly using prismatic maps is unsurprising, given their display complexity; what is surprising is that those who indicated a preference for prisms did not use them to achieve higher accuracy rates similar to the choropleth group. In other words, these participants showed a preference for the more complex prisms even though the prisms adversely affected their accuracy rates, thus supporting the presence of naïve cartography among the test participants.

5.4.3 Preference and Completion Time

Completion times, by individual map variable or by map combination, are not intended to represent a map's inherent efficiency. That is, short completion times were not necessarily expected to indicate a "better" or "worse" map. Instead, completion times were evaluated to gauge how the complexity of each map display, and how the potentially problematic characteristics of the 3D environment, affected map reading tasks. As an extension of this evaluation, map variables and combination preferences were expected to coincide with whichever resulted in the shortest completion times. Although participation was voluntary, it was assumed that most participants would want to complete all portions of the test as quickly as possible, and so completion time became a proxy for how efficient each map variable and combination was to read and extract information (*not* how accurately those variables and combinations were used).

The results of this analysis indicated that both the interaction of map medium and symbolization method, and the main effects of each on completion times, when separated by preference groups, are all significant. Participants who indicated a preference for low variable dimensionality (and less display complexity) logged a shorter mean completion time using maps containing those low-dimension variables. Also, those who preferred higher dimensionality (and more display complexity) logged a longer mean completion time using maps containing those high-dimension variables. This indicates is that preference for a particular map combination, and that map's display complexity, is influenced by more than the amount of time spent navigating and reading that particular map. Map preferences are shaped or determined by more than one variable.

5.5 Future Research Considerations

As stated in section 1.2, the primary objective of this experiment was to contrast the effectiveness of representing global thematic datasets on VGs versus 2D flat maps using two visually and dimensionally distinct symbolization methods. Under study in this thesis is the effectiveness of the selected map variables in facilitating task completion in the VG environment and whether the display complexity of the environment support or inhibit the application of these principles in comparison to the flat map environment. Within this research, using these four map variables, VGs did not test significantly worse or inferior to flat maps, which supports their use as an effective thematic mapping medium. However, the scope of this study is limited to just a few of the design principles used to facilitate thematic data display, and so the experiment findings have limited applicability to existing design guidelines. Future VG research must expand beyond the experimental design parameters of this research in order to provide conclusive evidence supporting or opposing VGs for thematic mapping purposes. Three important issues for future research consideration are discussed below.

The first issue to consider in any future VG research should be to complete a thorough assessment of a VG user's ability to effectively interpret global patterns and spatially correlated data displayed in the VG environment. Concerning the two basic uses of thematic maps listed in section 2.6.2, this thesis shows that VGs were effectively used to extract specific data about specific locations (use one), but an insufficient amount of data was collected to allow for a useful evaluation of the VGs' ability to represent overall patterns of the mapped data (use two). As the literature indicates the VG environment impedes global pattern inference (e.g., Harrower 2009), this topic warrants immediate attention.

The second future research topic concerns the variety of thematic symbolization options available to mapmakers. The major finding of this research, that symbolization dimensionality is a significant indicator of user performance and preference, is tempered by the fact that only two symbolization methods were used in this experiment. 2D choropleth symbolization is common-place in conventional cartography, and participants were generally expected to be familiar with this method. Prisms, on the other hand, are both seldom used and generally unsuitable for most thematic map displays (particularly static map displays). Cartographers must evaluate other thematic symbolization methods in the VG environment to arrive at broader conclusive evidence regarding symbol dimensionality and user performance. For example, Bleisch et al. (2008) and Bleisch (2011) show that some 2D and 3D symbolization methods can be effectively and efficiently utilized in VG environments, although neither studies focuses on their use to represent global thematic datasets. Future symbolization assessments within VG environments must take into account both thematic map uses.

The third issue concerns the working population accessed for these studies. As mentioned in section 3.3, the participant group recruited from the working population did not accurately represent the target population (i.e., all VG users). However, most VG users are likely novice or casual map users, their education levels range from elementary school through graduate school, and their ages from pre-teen to senior citizen. Future evaluations of the VG environment and capabilities should necessarily recruit a participant pool which accounts for as much of this demographic variety as feasible, or future evaluations should be divided up by user age, generation, or experience. Doing so will ensure that the results of future VG assessments are applicable to more than one VG user group.

CHAPTER 6: CONCLUSION

VGs have yet to pass through a formative phase of empirical, cartographic evaluation. Innovations to VG software have expanded their functional capabilities to allow for potentially unlimited geographic and cartographic applications, but conventional cartographers have much ground to cover if they intend to critique and shape the direction of these innovations. Popular use of VGs remains largely referential and exploratory, and does not yet encompass much thematic mapping. However, VGs are now making inroads as media for popular and professional scientific communication, and in time more and more users may choose to exploit the VG's thematic mapping capabilities. As the scientific community embraces VG technology, the cartographic community has a duty to keep pace with its pattern of use and offer appropriate guidance when necessary.

The VG environment possesses several characteristics of 3D environments known to encumber map reading and analysis tasks (e.g., occlusion, scale changes), as well as an inability to display the Earth's entire surface (and by extension, global datasets) in a single view. These traits, as well as others discussed in this thesis, are suspected to prevent efficient and effective map reading, but conclusive, confirmatory data remain scarce. This thesis shows that VGs can be used to effectively and efficiently display thematically mapped data, and that the detrimental characteristics of the 3D environment may be problematic only in certain circumstances (or when inappropriate symbolization methods are used).

As key as these findings may be, it is also necessary to acknowledge the built-in limitation of this research — there is insufficient data required to evaluate the participants' ability to interpret global patterns and spatially correlated data displayed in the VG environment. This thesis, and other, similar research (e.g., Bleisch et al. 2008; Bleisch 2011) focuses on specific data value extraction, comparison, and identification, which satisfies only half of the basic purpose of thematic maps. While showing tentative support for thematic mapping on VGs, the results of these studies will be irrelevant until both thematic mapping functions are thoroughly examined, as well as the effect dimensionality (and display complexity) increases have on VG user behavior and map reading abilities.

Since VGs are likely a permanent map medium, it is promising and encouraging that the results of this thesis suggest thematic mapping in VG environments is not wholly ineffective or inappropriate, that some useful applications may exist. These results are important considering that the VG's popularity acts as a new gateway to cartography, geography, and science in general. Because of this, it is important for cartographers to keep abreast with *how* VG technology is being applied, determine how VG technology fits within the cartographic landscape, and work to erase known deficiencies in our VG research. Hopefully, once normative guidelines regarding VG thematic mapping are established, these findings will allow us to fully exploit the evolving capabilities of VGs until a future where new, alternative map media technology (such as holograms) solve all the environmental limitations of the VG environment.

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APPENDIX A: CONSENT FORM

Evaluating the Effectiveness of Thematic Mapping on Virtual Globes

Travis White, Graduate Student
George McCleary, Professor
Department of Geography
University of Kansas

INTRODUCTION

The Department of Geography at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

This experiment evaluates how well humans can understand and analyze thematic datasets on virtual globes compared to traditional 2-D maps. By measuring map-reader performance in these environments, this study will meet two objectives, 1) to determine if virtual globes are an effective medium for displaying global thematic data, and 2) to establish guidelines for determining appropriate methods of thematic data representation on VGs either by adopting existing guidelines or developing new guidelines altogether.

PROCEDURES

You must be 18 years of age or older to participate. You will be asked to complete two questionnaires and a computer test comparing different map and map symbolization techniques. The first questionnaire will ask for general demographic data, such as sex, age, major and familiarity with maps and mapping concepts. The computer test will be recorded using screen capture software, but the session will not be audio or video recorded. The post-test questionnaire will gather your opinions on the contents of the test. All information will be saved to a personal computer, accessible only to the Principal Investigator and stored under lock and key when not in use.

All necessary equipment, hardware, and software will be provided by the Principal Investigator. All testing will occur in 310 Lindley Hall, a public computer laboratory. The entire test session is expected to last 20 minutes.

RISKS

The potential risk to you is minimal. At the most, participation in this study will result in fatigue due to the number of questions and the length of time it will take you to complete this study.

BENEFITS

The potential benefits of this study are twofold: first, the results may be used to improve the design and implementation of virtual globes; second, the results may help mapmakers improve existing cartographic design guidelines such that they account for mapping in virtual globe environments.

PAYMENT TO PARTICIPANTS

You will not receive monetary payment for participating in this experiment.

PARTICIPANT CONFIDENTIALITY

Your name will not be associated in any publication or presentation with the information collected about you or with the research findings from this study. Instead, the researcher(s) will use a study number or a pseudonym rather than your name. Your identifiable information will not be shared unless required by law or you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future."

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose further information collected about you, in writing, at any time, by sending your written request to: Travis White, 222 Lindley hall, 1475 Jayhawk Blvd., University of Kansas, Lawrence, KS 66045 .

If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above.

QUESTIONS ABOUT PARTICIPATION

Questions about procedures should be directed to the researcher(s) listed at the end of this consent form.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email mdenning@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_______________________________ _____________________

Type/Print Participant's Name Date

____

Participant's Signature

Researcher Contact Information

Travis M. White	Dr. George F. McCleary
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Geography Dept.	Geography Dept.
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APPENDIX B: PRE-TEST QUESTIONNAIRE

Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

Pre-test questions
Please provide answers to all questions before turning the page.

Name: ___________________________________

Enrolled Geography Course? (circle one): 102 / 105 / 111 / 358 / 558 / 726

Instructor: ________________________________

1. Sex (circle one): Male / Female
2. Age: __________
3. Year of Study (circle one):
   a. Freshman
   b. Sophomore
   c. Junior
   d. Senior
   e. Fifth-year
   f. Graduate student
4. Major: _______________________
5. Home state/country:_________________________________
6. Home county: _______________________________________
7. Do you wear glasses or contacts? (circle one): Yes / No
8. Are you colorblind? (circle one): Yes / No / Unsure
9. How often do you use paper maps? (circle one):
   a. Often (multiple times a week)
   b. Sometimes (less than once per week)
   c. Rarely (less than once per month)
   d. Never
10. How often do you use online maps (such as MapQuest)? (circle one):
    a. Often (multiple times a week)
    b. Sometimes (less than once per week)
    c. Rarely (less than once per month)
    d. Never
11. How often do you use Google Earth or other virtual globes? (circle one):
    a. Often (multiple times a week)
    b. Sometimes (less than once per week)
    c. Rarely (less than once per month)
    d. Never
12. Have you taken any cartography courses? (circle one): Yes / No
13. Do you have any experience making maps?: (circle one): Yes / No

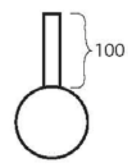
Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

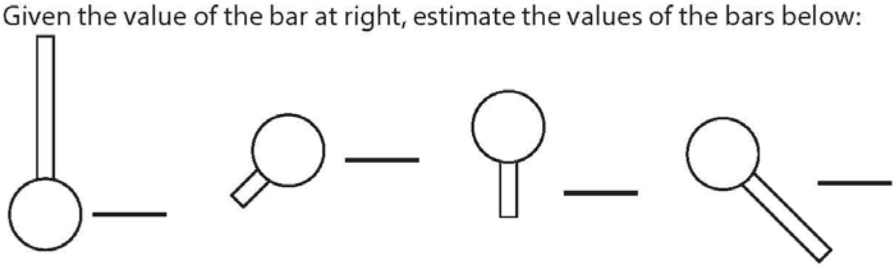
Pre-test questions: Graphic literacy
Please provide answers to all questions before turning the page.

Thank you for your participation!

The following series of questions are designed to assess your ability to interpret graphic variables. These questions will act as a "warm-up" to the experiment. When you are finished, please raise your hand so I can start you on the thematic map comparison test.

1. Given the value of the bar at right, estimate the values of the bars below:

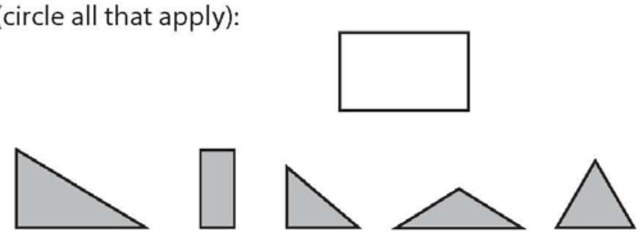




2. Rank the squares below in order from 1=light to 5=dark:

1)____ 2)____ 3)____ 4)____ 5)____

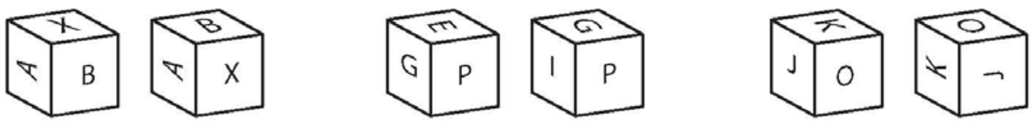
3. Which shapes below would be needed to fill the empty rectangle, assuming the shapes can be rotated to fit? (circle all that apply):



Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

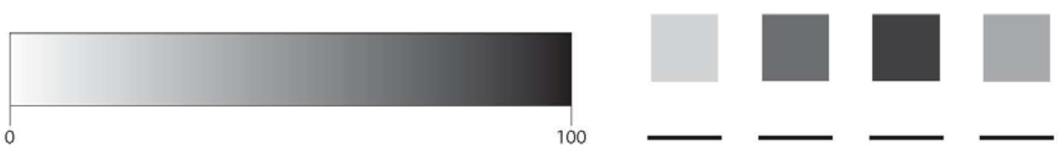
Pre-test questions: Graphic literacy
Please provide answers to all questions before turning the page.

4. Is the cube on the right a rotation of the cube on the left? Letters only appear once per die (circle one):

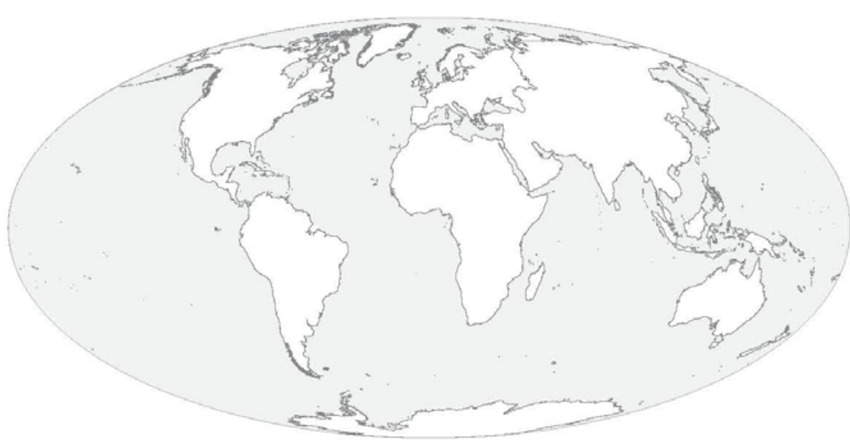


Yes / No   Yes / No   Yes / No

5. Using the gradient scale, estimate the values of the squares to the right:



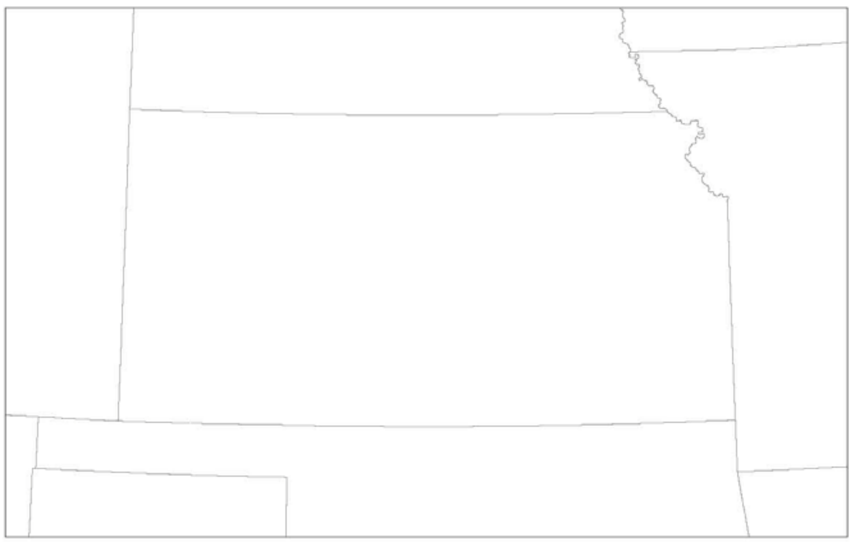
6. Label all of the continents in the picture below:



Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

Pre-test questions: Graphic literacy
Please provide answers to all questions before turning the page.

7. Label all of the states in the picture below:



Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

Pre-test questions

STOP!

You are ready to proceed to the map comparison test.

Please raise your hand and I will help you begin.

APPENDIX C: TEST INSTRUCTIONS, QUESTIONS, AND ANSWERS

Map 1
Before answering the questions, take some time to familiarize yourself with the data set. When you are ready to start the test, turn to the next page.

—+—+—+—

Task 1: Value Identification
Identify the one country with the highest or largest data value in the entire dataset.

—+—+—+—

Task 2: Equal Value
Identify a country in the Europe with a value approximately equal to Brazil (the largest country in South America). If there is none, indicate that in your answer.

—+—+—+—

Task 3: Variance
Identify the continent displaying the WIDEST distribution of data values (the LARGEST difference between its high and low values) (select one):

a. Asia
b. South America
c. Europe
d. North America
e. Africa

—+—+—+—

Task 4: Memory
This task will test your ability to remember key features of the **continents and the United States**. You have one minute to familiarize yourself with the dataset. When you are ready to proceed, **minimize the map window!!!** Now turn to the next page.

a. Identify the continent displaying the SMALLEST variation in data values (the smallest difference between its high and low value).

a. Asia
b. South America
c. Europe
d. North America
e. Africa
f. Unsure

b. Where does the value of the United States fall in the total range of data values? (mark approximate placement or Unsure):

Low |--| High

Unsure

Map 2

Before answering the questions, take some time to familiarize yourself with the data set. When you are ready to start the test, turn to the next page.

—+—+—+—

Task 1: Highest Value

Compare Australia and Greenland. Which country has a higher or larger data value? (select one):

a. Australia
b. Greenland
c. Equal

—+—+—+—

Task 2: Equal Value

Identify a country in South America with a value approximately equal to Russia (the largest country in Europe and Asia). If there is none, indicate that in your answer.

—+—+—+—

Task 3: Variance

Identify the continent displaying the SMALLEST variation in data values (the smallest difference between its high and low value).

a. Asia
b. South America
c. Europe
d. North America
e. Africa

—+—+—+—

Task 4: Memory

This task will test your ability to remember key features of the **continents**. You have one minute to familiarize yourself with the dataset. When you are ready to proceed, **minimize the map window!!!** Now turn to the next page.

a. Identify the continent displaying the WIDEST distribution of data values (the LARGEST difference between its high and low values) (select one):

a. Asia
b. South America
c. Europe
d. North America
e. Africa
f. Unsure

b. Was the value of Antarctica approximately equal to the value of Australia? (select one):

Yes / No / Unsure

Map 3

Before answering the questions, take some time to familiarize yourself with the data set. When you are ready to start the test, turn to the next page.

—+—+—+—

Task 1: Highest Value

Identify the country with the highest data value.

—+—+—+—

Task 2: Equal Value

Identify a country in South America with a value approximately equal to the United Kingdom (island in northwest Europe). If there is none, indicate that in your answer.

—+—+—+—

Task 3: Variance

If the range of possible data values for the **entire** data set is 1 to 100, estimate the total range of values in **Africa** (the difference between the largest and smallest data values).

—+—+—+—

Task 4: Memory

This task will test your ability to remember key features of the **North America**. You have one minute to familiarize yourself with the dataset. When you are ready to proceed, **minimize the map window!!!** Now turn to the next page.

a. Identify which North American country displayed the highest or largest data value. If unsure, indicate that in your answer.

b. Was the value of the United States similar to the value of Canada? (select one):

Yes / No / Unsure

Map 4

Before answering the questions, take some time to familiarize yourself with the data set. When you are ready to start the test, turn to the next page.

—+—+—+—

Task 1: Highest Value

Compare Nepal (in Asia between China and India) and Bolivia (in South America between Brazil and Argentina). Which country has a higher or larger data value?

—+—+—+—

Task 2: Equal Value

Compare Japan (island in East Asia) and the United Kingdom (island in northwest Europe). Are their data values approximately equal?

—+—+—+—

Task 3: Variance

If the range of possible data values for the **entire** data set is 1 to 100, estimate the difference in values between the **United States and Canada**.

—+—+—+—

Task 4: Memory

This task will test your ability to remember key features of the **entire map**. You have one minute to familiarize yourself with the dataset. When you are ready to proceed, **minimize the map window!!!** Now turn to the next page.

a. Identify the country displaying the highest data value. If unsure, indicate that in your answer.

b. Was the value of the United States similar to the value of Australia? (select one):

Yes / No / Unsure

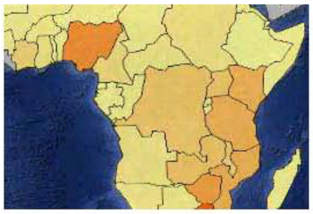
Correct Answers to all four datasets:

		Questions	Dataset 1	Dataset 2	Dataset 3	Dataset 4
Map 1	Task 1	1.1	Uzbekistan	Tanzania	Honduras	Norway
	Task 2	1.2	Brazil=12	Brazil=7	Brazil=88	Brazil=7
	Task 3	1.3_1	a. Asia	e. Africa	d. North Am	c. Europe
		1.3_2	a. Asia	e. Africa	a. Asia	c. Europe
	Task 4	1.4a_1	d. North Am	b. South Am	b. South Am	b. South Am
		1.4a_2	d. North Am	d. North Am	d. North Am	d. North Am
		1.4b	USA=7	USA=20	USA=3	USA=30
Map 2	Task 1	2.1	a. Australia	b. Greenland	b. Greenland	a Australia
	Task 2	2.2	Russia=25	Russia=15	Russia=52	Russia=84
	Task 3	2.3_1	d. North Am	b. South Am	b. South Am	b. South Am
		2.3_2	d. North Am	d. North Am	d. North Am	d. North Am
	Task 4	2.4a_1	a. Asia	e. Africa	d. North Am	c. Europe
		2.4a_2	a. Asia	e. Africa	a. Asia	c. Europe
		2.4b	No (85, 0)	Yes (2, 0)	Yes (1, 0)	No (87, 0)
Map 3	Task 1	3.1	Uzbekistan	Tanzania	Honduras	Norway
	Task 2	3.2	UK=6	UK=90	UK=47	UK=26
	Task 3	3.3	1-89 (88)	1-100 (99)	1-88 (87)	2-90 (88)
	Task 4	3.4a_1	Guatemala (73)	Honduras (81)	Honduras (100)	Haiti (90)
		3.4a_2	Mexico (13)	Mexico (79)	Mexico (55)	Mexico (33)
		3.4b	Yes (7, 9)	No (20, 33)	No (3, 36)	Yes (30, 31)
Map 4	Task 1	4.1	Nepal	Nepal	Bolivia	Bolivia
	Task 2	4.2	No (17, 6)	Yes (89, 90)	Yes (43, 47)	No (39, 26)
	Task 3	4.3	7-9 (2)	20-33 (13)	3-36 (33)	30-31 (1)
	Task 4	4.4a	Uzbekistan	Tanzania	Honduras	Norway

APPENDIX D: POST-TEST QUESTIONNAIRE

Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

Exit Questionnaire
Please answer all questions before turning the page.



Choropleth Map

Prism Map

1. Rate the effectiveness of each symbolization method at displaying data values:

	Ineffective		Neutral		Effective
Choropleth	1	2	3	4	5
Prism	1	2	3	4	5

2. Rate each medium's ability to display choropleth data:

	Ineffective		Neutral		Effective
Flat map	1	2	3	4	5
Virtual globe	1	2	3	4	5

3. Rate each medium's ability to display prismatic data:

	Ineffective		Neutral		Effective
Flat map	1	2	3	4	5
Virtual globe	1	2	3	4	5

4. Which map medium do you prefer? (circle one):
   a. Choropleth
   b. Prism
   c. No preference

5. Which symbolization method do you prefer? (circle one):
   a. Choropleth
   b. Prism
   c. No preference

Experiment: Thematic Mapping Comparison Test
Principal Investigator: Travis White (tmwhite@ku.edu)
Where: Computer Lab, 310 Lindley Hall

Exit Questionnaire
Please answer all questions before turning the page.

Choropleth Map

Prism Map

6. Which symbolization method was more effective at representing data values? (circle one):

a. Prism
b. Choropleth
c. Same
d. Don't know

7. Rank your preference for each map medium-symbol combination (1 = highest, 4=lowest):

1.____	a. Flat map - choropleth
2.____	b. Flat map - prism
3.____	c. Virtual globe - choropleth
4.____	d. Virtual globe - prism

8. How helpful was the virtual globe environment to exploring the each map type?

	Unhelpful		Neutral		Helpful
Choropleth	1	2	3	4	5
Prism	1	2	3	4	5

9. Overall, which medium do you think leads to better performance?

a. Virtual Globe
b. Flat Map
c. Same
d. Don't know

APPENDIX E: ARCGLOBE AND ARCSCENE TUTORIAL

Software Tutorial: ESRI ArcScene and ArcGlobe

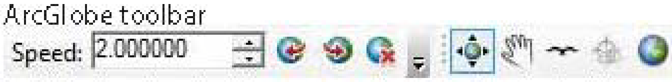
Please use this guide to familiarize yourself with the two map viewing applications used in this experiment, ArcScene and ArcGlobe. Both use the same basic computer mouse controls and command buttons found in the toolbar at the top of the display.

The computer mouse can be used to complete every map task in the experiment.

ArcScene toolbar

ArcScene is a mapping program similar to Google Maps, except that you can tilt the view.

ArcGlobe toolbar



ArcGlobe is a virtual globe program similar to Google Earth in appearance and basic control.

The important controls: LOOK, MOVE, and the mouse SCROLL WHEEL

LOOK

Use the LOOK joystick (with the globe) to look around from a single vantage point, as if you were turning your head. Press down on the left mouse button and move in any direction to change your view.

MOVE

Use the Move hand to move your position from one place to another.

SCROLL WHEEL

Use the scroll to zoom:

1. Zoom in (use the scroll wheel to scroll away from you OR double-click the left button)
2. Zoom out (use the scroll wheel to scroll towards you OR double-click the right button)

SPIN THE GLOBE

To spin the globe, click either globe icon that has an arrow. To stop the rotation, simple click on the globe icon with the red "X"

APPENDIX F: USER PERFORMANCE DATA

Overall Accuracy Rate Data:

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Overall_AccRate	50	.118	.882	.57176	.150343	.023	-.469	.337	.583	.662
NoMem_AccRate	50	.100	.900	.65000	.160675	.026	-.477	.337	1.542	.662
Mem_AccRate	50	.000	.857	.46000	.208703	.044	-.317	.337	-.410	.662
Valid N (listwise)	50									

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Overall_AccRate	.132	50	.030	.969	50	.217
NoMem_AccRate	.158	50	.003	.911	50	.001
Mem_AccRate	.183	50	.000	.945	50	.022

Paired Samples T-test: memory & non-memory mean accuracy rates:

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	NoMem_AccRate	.65000	50	.160675	.022723
	Mem_AccRate	.46000	50	.208703	.029515

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	NoMem_AccRate & Mem_AccRate	50	.387	.006

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	NoMem_AccRate - Mem_AccRate	.190000	.208388	.029471	.130777	.249223	6.447	49	.000

Overall accuracy rates divided by map combination:

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
FC_AccRate	49	.000	1.000	.81293	.253751	.064	-1.151	.340	.697	.668
FP_AccRate	50	.000	1.000	.56667	.341731	.117	-.095	.337	-1.026	.662
GC_AccRate	50	.000	1.000	.71333	.277746	.077	-.493	.337	-.346	.662
GP_AccRate	50	.000	1.000	.50667	.341665	.117	-.115	.337	-.942	.662
Valid N (listwise)	49									

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
FC_AccRate	.361	49	.000	.739	49	.000
FP_AccRate	.201	49	.000	.874	49	.000
GC_AccRate	.274	49	.000	.813	49	.000
GP_AccRate	.153	49	.006	.888	49	.000

a. Lilliefors Significance Correction

Repeated measures ANOVA: accuracy rates x map combination

Descriptive Statistics

	Mean	Std. Deviation	N
Flat_AccRate	.67500	.236381	50
Globe_AccRate	.61633	.219164	50
Choro_AccRate	.74800	.230637	50
Prism_AccRate	.53500	.237266	50

Mauchly's Test of Sphericity[a]

Measure: Accuracy

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
MedAcc	1.000	.000	0	.	1.000	1.000	1.000
SymbolAcc	1.000	.000	0	.	1.000	1.000	1.000
MedAcc * SymbolAcc	1.000	.000	0	.	1.000	1.000	1.000

Tests of Within-Subjects Effects

Measure: Accuracy

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MedAcc	Sphericity Assumed	.001	1	.001	1.313	.257	.026
Error(MedAcc)	Sphericity Assumed	.032	49	.001			
SymbolAcc	Sphericity Assumed	.923	1	.923	23.454	.000	.324
Error(SymbolAcc)	Sphericity Assumed	1.927	49	.039			
MedAcc * SymbolAcc	Sphericity Assumed	.298	1	.298	5.184	.027	.096
Error(MedAcc*SymbolAcc)	Sphericity Assumed	2.814	49	.057			

Tests of Between-Subjects Effects

Measure: Accuracy   Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	82.840	1	82.840	714.357	.000	.936
Error	5.682	49	.116			

Pairwise Comparisons

Measure: AccRate

(I) ComboAcc	(J) ComboAcc	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
	2	.245*	.054	.000	.095	.394
1	3	.099	.047	.249	-.031	.228
	4	.296*	.060	.000	.130	.462
	1	-.245*	.054	.000	-.394	-.095
2	3	-.146	.067	.203	-.330	.038
	4	.051	.069	1.000	-.139	.241
	1	-.099	.047	.249	-.228	.031
3	2	.146	.067	.203	-.038	.330
	4	.197*	.067	.030	.013	.381
	1	-.296*	.060	.000	-.462	-.130
4	2	-.051	.069	1.000	-.241	.139
	3	-.197*	.067	.030	-.381	-.013

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Overall value estimation accuracy separated by value estimation question:

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Task1.2b	42	-43	31	-1.95	10.831	-.702	.365	5.735	.717
Task2.2b	45	-32	38	1.33	14.695	.700	.354	.980	.695
Task3.2b	42	-65	73	7.02	23.416	.082	.365	2.218	.717
Task3.3	50	-48	18	-8.14	15.209	-.681	.337	.387	.662
Task4.3	50	-33	49	3.58	13.734	-.056	.337	2.927	.662
Valid N (listwise)	35								

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Task1.2b	.178	42	.002	.878	42	.000
Task2.2b	.172	45	.002	.938	45	.018
Task3.2b	.187	42	.001	.930	42	.013
Task3.3	.224	50	.000	.935	50	.009
Task4.3	.196	50	.000	.912	50	.001

a. Lilliefors Significance Correction

Question 2.2b ANOVA:

Descriptive Statistics

Dependent Variable: Task2.2b

M2_M	M2_S	Mean	Std. Deviation	N
Flat Map	Choropleth	10.38	14.657	8
	Prism	3.00	18.983	12
	Total	5.95	17.364	20
Virtual Globe	Choropleth	3.85	9.728	13
	Prism	-9.08	8.670	12
	Total	-2.36	11.191	25
Total	Choropleth	6.33	11.939	21
	Prism	-3.04	15.697	24
	Total	1.33	14.695	45

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Task2.2b

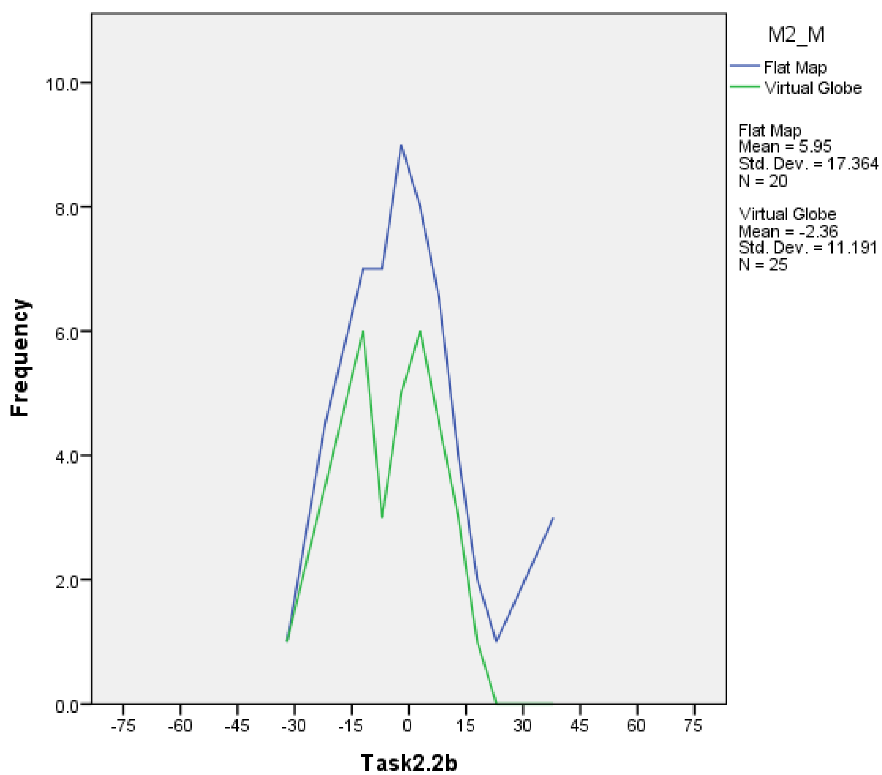
F	df1	df2	Sig.
2.924	3	41	.045

Tests of Between-Subjects Effects

Dependent Variable: Task2.2b

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2071.516[a]	3	690.505	3.810	.017	.218
Intercept	179.669	1	179.669	.991	.325	.024
M2_M	939.834	1	939.834	5.186	.028	.112
M2_S	1118.512	1	1118.512	6.172	.017	.131
M2_M * M2_S	83.704	1	83.704	.462	.501	.011
Error	7430.484	41	181.231			
Total	9582.000	45				
Corrected Total	9502.000	44				

a. R Squared = .218 (Adjusted R Squared = .161)



Independent Samples T-Test: Accuracy rate grouped by English literacy

Group Statistics

	LangBarr	N	Mean	Std. Deviation	Std. Error Mean
NoMem_AccRate	Yes	6	.51667	.231661	.094575
	No	44	.66818	.142686	.021511

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
NoMem_AccRate	Equal variances assumed	2.650	.110	-2.255	48	.029	-.151515	.067179	-.286588	-.016442
	Equal variances not assumed			-1.562	5.529	.173	-.151515	.096991	-.393831	.090800

Independent Samples T-Test: Accuracy rate grouped by geographic literacy:

Group Statistics

	GeogIllit	N	Mean	Std. Deviation	Std. Error Mean
NoMem_AccRate	Illiterate	11	.55455	.175292	.052853
	Literate	39	.67692	.147722	.023654

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
NoMem_AccRate	Equal variances assumed	.002	.969	-2.330	48	.024	-.122378	.052532	-.228000	-.016756
	Equal variances not assumed			-2.113	14.257	.053	-.122378	.057904	-.246361	.001605

Repeated Measures ANOVA: Accuracy rate grouped by geographic literacy and Map Combo

Descriptive Statistics

	GeogIllit	Mean	Std. Deviation	N
Flat_AccRate	Illiterate	.58939	.260264	11
	Literate	.69915	.226947	39
	Total	.67500	.236381	50
Globe_AccRate	Illiterate	.66061	.174368	11
	Literate	.60385	.230670	39
	Total	.61633	.219164	50
Choro_AccRate	Illiterate	.71818	.162866	11
	Literate	.75641	.247550	39
	Total	.74800	.230637	50
Prism_AccRate	Illiterate	.50909	.231104	11
	Literate	.54231	.241427	39
	Total	.53500	.237266	50

Mauchly's Test of Sphericity[a]

Measure: GeogLit

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
AccRate	.040	150.313	5	.000	.646	.687	.333

Tests of Within-Subjects Effects

Measure: GeogLit

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AccRate	Sphericity Assumed	.772	3	.257	7.965	.000	.142
	Greenhouse-Geisser	.772	1.938	.399	7.965	.001	.142
AccRate * GeogIllit	Sphericity Assumed	.120	3	.040	1.235	.299	.025
	Greenhouse-Geisser	.120	1.938	.062	1.235	.295	.025
Error(AccRate)	Sphericity Assumed	4.654	144	.032			
	Greenhouse-Geisser	4.654	93.024	.050			

Levene's Test of Equality of Error Variances[a]

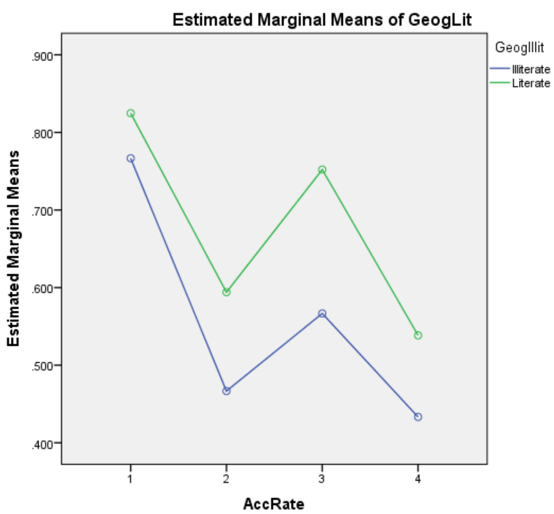
	F	df1	df2	Sig.
Flat_AccRate	.252	1	48	.618
Globe_AccRate	.562	1	48	.457
Choro_AccRate	.384	1	48	.538
Prism_AccRate	.000	1	48	.996

Tests of Between-Subjects Effects

Measure: GeogLit

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	55.333	1	55.333	470.162	.000	.907
GeogIllit	.033	1	.033	.282	.598	.006
Error	5.649	48	.118			



Independent Samples T-Test: Accuracy rate grouped by mapping experience

Tests of Normality

	Experience	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
NoMem_AccRate	Yes	.144	26	.178	.917	26	.039
	No	.208	24	.008	.868	24	.005

a. Lilliefors Significance Correction

Group Statistics

	Experience	N	Mean	Std. Deviation	Std. Error Mean
NoMem_AccRate	Yes	26	.69615	.150946	.029603
	No	24	.60000	.158800	.032415

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
NoMem_AccRate	Equal variances assumed	.454	.504	2.195	48	.033	.096154	.043807	.008073	.184235
	Equal variances not assumed			2.190	47.175	.033	.096154	.043898	.007851	.184457

Repeated measures ANOVA: Accuracy rate grouped by mapping experience and map combo:

Descriptive Statistics

	Experience	Mean	Std. Deviation	N
FC_AccRate	Yes	.84667	.240177	25
	No	.77778	.267691	24
	Total	.81293	.253751	49
FP_AccRate	Yes	.66667	.353553	25
	No	.46528	.310754	24
	Total	.56803	.345135	49
GC_AccRate	Yes	.72667	.280046	25
	No	.70139	.286488	24
	Total	.71429	.280542	49
GP_AccRate	Yes	.59333	.315788	25
	No	.43750	.346872	24
	Total	.51701	.337208	49

Mauchly's Test of Sphericity[a]

Measure: MappingExp

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
AccRate	.783	11.204	5	.048	.888	.966	.333

Tests of Within-Subjects Effects

Measure: MappingExp

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AccRate	Sphericity Assumed	2.722	3	.907	9.822	.000	.173
	Greenhouse-Geisser	2.722	2.664	1.022	9.822	.000	.173
	Huynh-Feldt	2.722	2.899	.939	9.822	.000	.173
	Lower-bound	2.722	1.000	2.722	9.822	.003	.173
AccRate * Experience	Sphericity Assumed	.236	3	.079	.852	.468	.018
	Greenhouse-Geisser	.236	2.664	.089	.852	.457	.018
	Huynh-Feldt	.236	2.899	.081	.852	.464	.018
	Lower-bound	.236	1.000	.236	.852	.361	.018
Error(AccRate)	Sphericity Assumed	13.025	141	.092			
	Greenhouse-Geisser	13.025	125.187	.104			
	Huynh-Feldt	13.025	136.235	.096			
	Lower-bound	13.025	47.000	.277			

Tests of Between-Subjects Effects

Measure: MappingExp

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	83.263	1	83.263	940.836	.000	.952
Experience	.624	1	.624	7.048	.011	.130
Error	4.159	47	.088			

Pairwise Comparisons

Measure: MappingExp

(I) AccRate	(J) AccRate	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.246*	.054	.000	.097	.395
	3	.098	.048	.266	-.033	.229
	4	.297*	.061	.000	.130	.464
2	1	-.246*	.054	.000	-.395	-.097
	3	-.148	.066	.184	-.331	.035
	4	.051	.070	1.000	-.142	.243
3	1	-.098	.048	.266	-.229	.033
	2	.148	.066	.184	-.035	.331
	4	.199*	.067	.028	.014	.383
4	1	-.297*	.061	.000	-.464	-.130
	2	-.051	.070	1.000	-.243	.142
	3	-.199*	.067	.028	-.383	-.014

Repeated Measures ANOVA: Accuracy rate grouped by mapping experience and map medium:

Descriptive Statistics

	Experience	Mean	Std. Deviation	N
Flat_AccRate	Yes	.68462	.239162	26
	No	.66458	.238013	24
	Total	.67500	.236381	50
Globe_AccRate	Yes	.65064	.218758	26
	No	.57917	.218042	24
	Total	.61633	.219164	50

Mauchly's Test of Sphericity[a]

Measure: MappingExp

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
AccRate	1.000	.000	0	.	1.000	1.000	1.000

Tests of Within-Subjects Effects

Measure: MappingExp

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AccRate	Sphericity Assumed	.089	1	.089	1.933	.171	.039
	Greenhouse-Geisser	.089	1.000	.089	1.933	.171	.039
	Huynh-Feldt	.089	1.000	.089	1.933	.171	.039
	Lower-bound	.089	1.000	.089	1.933	.171	.039
AccRate * Experience	Sphericity Assumed	.017	1	.017	.359	.552	.007
	Greenhouse-Geisser	.017	1.000	.017	.359	.552	.007
	Huynh-Feldt	.017	1.000	.017	.359	.552	.007
	Lower-bound	.017	1.000	.017	.359	.552	.007
Error(AccRate)	Sphericity Assumed	2.209	48	.046			
	Greenhouse-Geisser	2.209	48.000	.046			
	Huynh-Feldt	2.209	48.000	.046			
	Lower-bound	2.209	48.000	.046			

Tests of Between-Subjects Effects

Measure: MappingExp

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	41.504	1	41.504	707.975	.000	.937
Experience	.052	1	.052	.891	.350	.018
Error	2.814	48	.059			

Repeated Measures ANOVA: Accuracy rate grouped by mapping experience and Symbol:

Descriptive Statistics

	Experience	Mean	Std. Deviation	N
Choro_AccRate	Yes	.72179	.231650	26
	No	.77639	.231040	24
	Total	.74800	.230637	50
Prism_AccRate	Yes	.60385	.240569	26
	No	.46042	.214161	24
	Total	.53500	.237266	50

Mauchly's Test of Sphericity[a]

Measure: MappingExp

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
AccRate	1.000	.000	0	.	1.000	1.000	1.000

Tests of Within-Subjects Effects

Measure: MappingExp

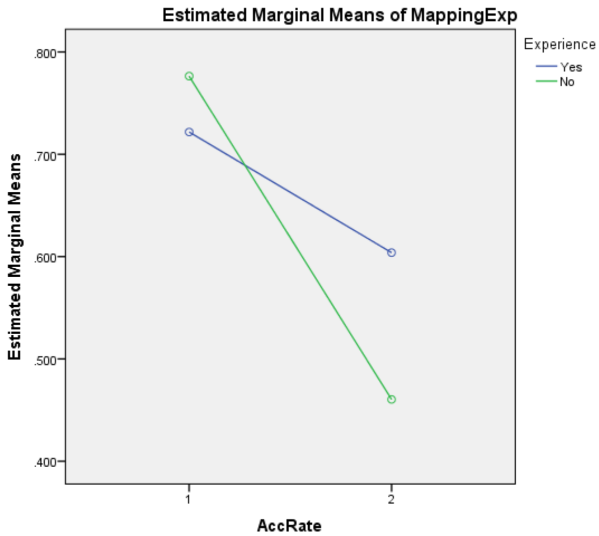
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AccRate	Sphericity Assumed	1.175	1	1.175	24.825	.000	.341
	Greenhouse-Geisser	1.175	1.000	1.175	24.825	.000	.341
	Huynh-Feldt	1.175	1.000	1.175	24.825	.000	.341
	Lower-bound	1.175	1.000	1.175	24.825	.000	.341
AccRate * Experience	Sphericity Assumed	.245	1	.245	5.170	.027	.097
	Greenhouse-Geisser	.245	1.000	.245	5.170	.027	.097
	Huynh-Feldt	.245	1.000	.245	5.170	.027	.097
	Lower-bound	.245	1.000	.245	5.170	.027	.097
Error(AccRate)	Sphericity Assumed	2.272	48	.047			
	Greenhouse-Geisser	2.272	48.000	.047			
	Huynh-Feldt	2.272	48.000	.047			
	Lower-bound	2.272	48.000	.047			

Tests of Between-Subjects Effects

Measure: MappingExp

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	40.973	1	40.973	702.583	.000	.936
Experience	.049	1	.049	.844	.363	.017
Error	2.799	48	.058			



Descriptive Statistics

Dependent Variable: NoMem_AccRate

Experience	Mean	Std. Deviation	N
Yes	.69615	.150946	26
No	.60000	.158800	24
Total	.65000	.160675	50

Accuracy Sorted by Patience

Tests of Normality

	Impatience_1	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
NoMem_AccRate	Impatient	.216	11	.162	.862	11	.062
	Patient	.407	6	.002	.640	6	.001
	Uncertain	.210	33	.001	.893	33	.003

a. Lilliefors Significance Correction

Descriptive Statistics

Dependent Variable: NoMem_AccRate

Impatience_1	Mean	Std. Deviation	N
Impatient	.66364	.156670	11
Patient	.80000	.154919	6
Uncertain	.61818	.150944	33
Total	.65000	.160675	50

Levene's Test of Equality of Error Variances[a]

Dependent Variable: NoMem_AccRate

F	df1	df2	Sig.
.408	2	47	.668

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Impatience_1

Tests of Between-Subjects Effects

Dependent Variable: NoMem_AccRate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.170[a]	2	.085	3.660	.033	.135
Intercept	15.055	1	15.055	646.458	.000	.932
Impatience_1	.170	2	.085	3.660	.033	.135
Error	1.095	47	.023			
Total	22.390	50				
Corrected Total	1.265	49				

a. R Squared = .135 (Adjusted R Squared = .098)

Pairwise Comparisons

Dependent Variable: NoMem_AccRate

(I) Impatience_1	(J) Impatience_1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Impatient	Patient	-.136	.077	.254	-.329	.056
	Uncertain	.045	.053	1.000	-.086	.177
Patient	Impatient	.136	.077	.254	-.056	.329
	Uncertain	.182*	.068	.030	.014	.350
Uncertain	Impatient	-.045	.053	1.000	-.177	.086
	Patient	-.182*	.068	.030	-.350	-.014

Accuracy Sorted by Participant Volunteer Status

Tests of Normality

	Subject_Status	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
NoMem_AccRate	Volunteer	.169	14	.200*	.895	14	.096
	Extra Credit	.173	36	.008	.902	36	.004

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptive Statistics

Dependent Variable: NoMem_AccRate

Subject_Status	Mean	Std. Deviation	N
Volunteer	.72857	.143734	14
Extra Credit	.61944	.158239	36
Total	.65000	.160675	50

Levene's Test of Equality of Error Variances[a]

Dependent Variable: NoMem_AccRate

F	df1	df2	Sig.
.032	1	48	.859

Tests of Between-Subjects Effects

Dependent Variable: NoMem_AccRate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.120[a]	1	.120	5.032	.030	.095
Intercept	18.317	1	18.317	767.894	.000	.941
Subject_Status	.120	1	.120	5.032	.030	.095
Error	1.145	48	.024			
Total	22.390	50				
Corrected Total	1.265	49				

a. R Squared = .095 (Adjusted R Squared = .076)

Ranks

	Subject_Status	N	Mean Rank	Sum of Ranks
NoMem_AccRate	Volunteer	14	31.50	441.00
	Extra Credit	35	22.40	784.00
	Total	49		

Test Statistics[a]

	NoMem_AccRate
Mann-Whitney U	154.000
Wilcoxon W	784.000
Z	-2.069
Asymp. Sig. (2-tailed)	.039

a. Grouping Variable: Subject_Status

Appendix G: Completion Time Data

Adjusted Completion Time data:

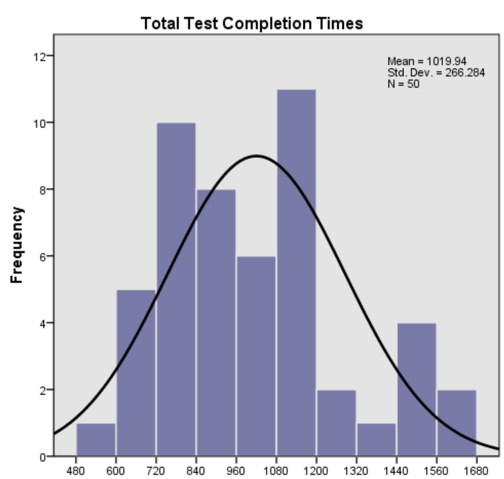
Descriptives

			Statistic	Std. Error
Total	Mean		1019.94	37.658
	95% Confidence Interval for Mean	Lower Bound	944.26	
		Upper Bound	1095.62	
	5% Trimmed Mean		1011.90	
	Median		1018.50	
	Variance		70907.364	
	Std. Deviation		266.284	
	Minimum		521	
	Maximum		1607	
	Range		1086	
	Interquartile Range		354	
	Skewness		.524	.337
	Kurtosis		-.276	.662

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total	.116	50	.090	.957	50	.068

a. Lilliefors Significance Correction



Repeated Measures ANOVA: Completion times grouped by map combination

Descriptive Statistics

	Mean	Std. Deviation	N
FC_TotTime	213.49	60.388	49
FP_TotTime	282.06	108.350	49
GC_TotTime	229.10	57.406	49
GP_TotTime	286.22	100.596	49

Mauchly's Test of Sphericity[a]

Measure: TestTime

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Combo	.656	19.729	5	.001	.790	.834	.333

Tests of Within-Subjects Effects

Measure: TestTime

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Combo	Sphericity Assumed	199933.485	3	66644.495	17.011	.000	.262
	Greenhouse-Geisser	199933.485	2.371	84308.578	17.011	.000	.262
	Huynh-Feldt	199933.485	2.503	79882.624	17.011	.000	.262
	Lower-bound	199933.485	1.000	199933.485	17.011	.000	.262
Error(Combo)	Sphericity Assumed	564152.265	144	3917.724			
	Greenhouse-Geisser	564152.265	113.830	4956.114			
	Huynh-Feldt	564152.265	120.136	4695.933			
	Lower-bound	564152.265	48.000	11753.172			

Tests of Between-Subjects Effects

Measure: TestTime

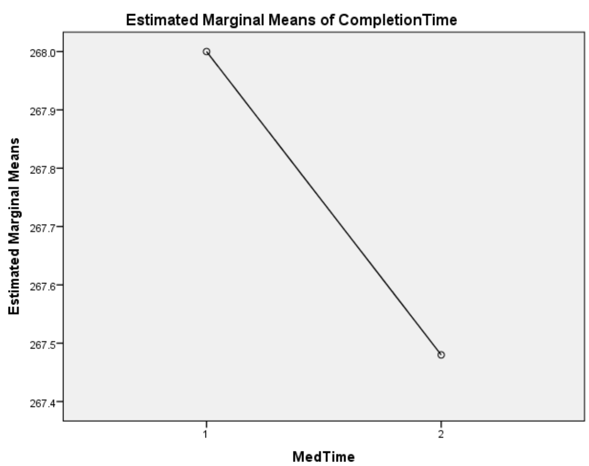
Transformed Variable: Average

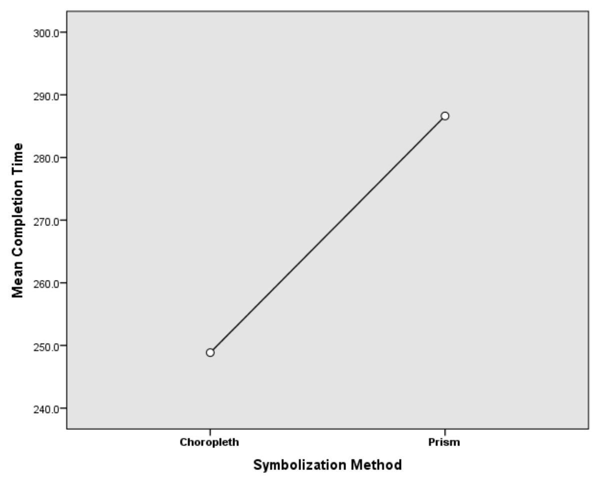
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	12517949.434	1	12517949.434	734.270	.000	.939
Error	818311.816	48	17048.163			

Pairwise Comparisons

Measure: TestTime

(I) Combo	(J) Combo	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-68.571*	15.088	.000	-110.095	-27.048
	3	-15.612	8.542	.443	-39.120	7.895
	4	-72.735*	11.184	.000	-103.512	-41.957
2	1	68.571*	15.088	.000	27.048	110.095
	3	52.959*	14.416	.004	13.285	92.634
	4	-4.163	14.217	1.000	-43.288	34.961
3	1	15.612	8.542	.443	-7.895	39.120
	2	-52.959*	14.416	.004	-92.634	-13.285
	4	-57.122*	11.127	.000	-87.743	-26.502
4	1	72.735*	11.184	.000	41.957	103.512
	2	4.163	14.217	1.000	-34.961	43.288
	3	57.122*	11.127	.000	26.502	87.743





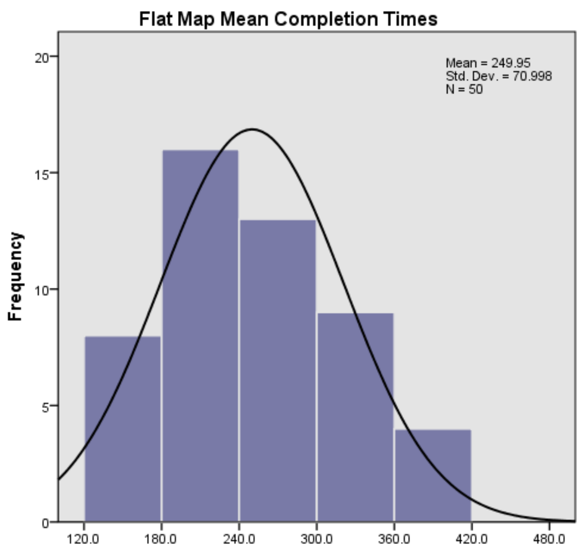
Paired Samples T-Tests: Completion times grouped by map medium:

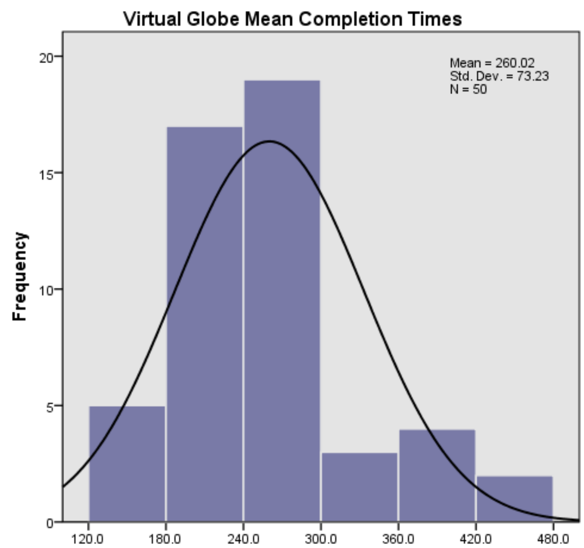
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Flat_MeanTime	.106	50	.200*	.965	50	.140
Globe_MeanTime	.115	50	.097	.939	50	.013

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Flat_MeanTime	249.950	50	70.9977	10.0406
	Globe_MeanTime	260.020	50	73.2305	10.3564

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Flat_MeanTime & Globe_MeanTime	50	.704	.000

Paired Samples Test

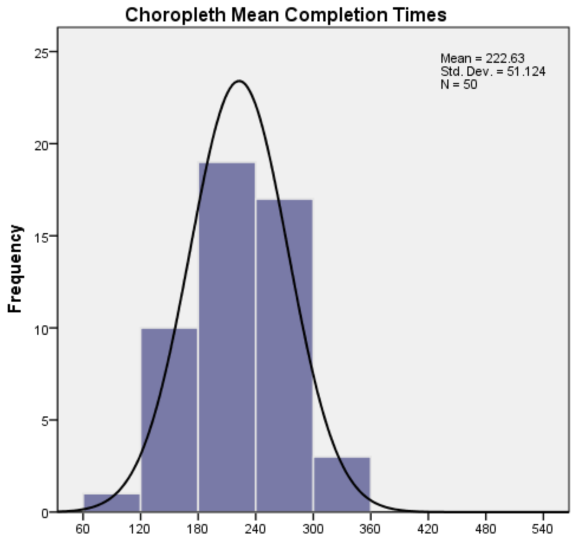
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Flat_MeanTime - Globe_MeanTime	-10.0700	55.4970	7.8485	-25.8421	5.7021	-1.283	49	.206

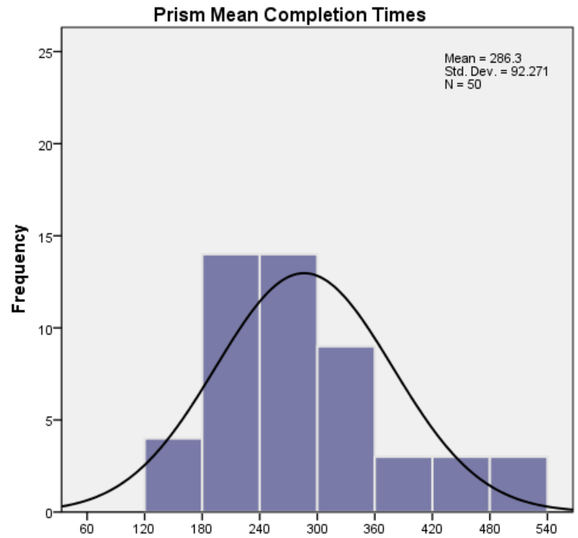
Paired Samples T-Tests: Completion times grouped by symbolization method:

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Choro_MeanTime	.129	50	.037	.972	50	.279
Prism_MeanTime	.117	50	.082	.937	50	.010

a. Lilliefors Significance Correction





Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Choro_MeanTime	222.63	50	51.124	7.230
	Prism_MeanTime	286.30	50	92.271	13.049

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Choro_MeanTime & Prism_MeanTime	50	.655	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Choro_MeanTime - Prism_MeanTime	-63.670	70.323	9.945	-83.656	-43.684	-6.402	49	.000

Completion time and Accuracy Rate Correlation

Descriptive Statistics

	Mean	Std. Deviation	N
Accur_Rate	.5717647246	.15034269255	50
Time_Total	1072.00	331.545	50

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Accur_Tot	50	2	15	9.72	2.556	6.532	-.469	.337	.583	.662
Accur_Rate	50	.11764706	.88235295	.5717647246	.15034269255	.023	-.469	.337	.583	.662
Time_Total	50	521	2101	1072.00	331.545	109921.837	1.134	.337	1.638	.662
Valid N (listwise)	50									

Exploration Times and Memory Accuracy Data

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mem_AccRate	.180	52	.000	.943	52	.015
Explore	.111	52	.155	.967	52	.160

a. Lilliefors Significance Correction

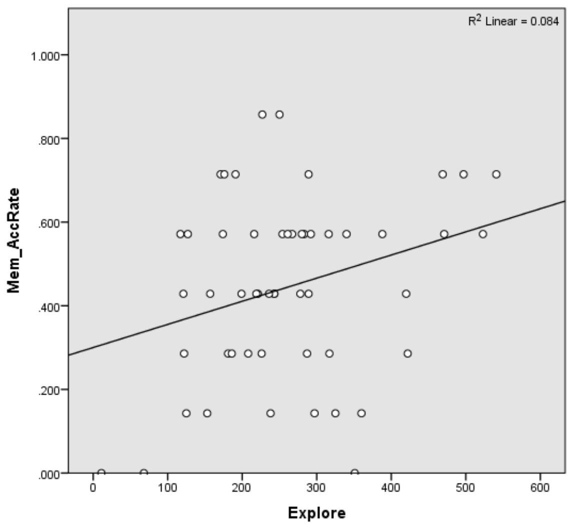
Descriptive Statistics

	Mean	Std. Deviation	N
Mem_AccRate	.44505	.218500	52
Explore	261.98	114.789	52

Correlations

		Mem_AccRate	Explore
Mem_AccRate	Pearson Correlation	1	.290*
	Sig. (2-tailed)		.037
	N	52	52
Explore	Pearson Correlation	.290*	1
	Sig. (2-tailed)	.037	
	N	52	52

*. Correlation is significant at the 0.05 level (2-tailed).



Appendix H: Preference

Post-Test Questionnaire Responses:

Statistics

		Post_Q4	Post_Q5	Post_Q7a	Post_Q7b	Post_Q7c	Post_Q7d
N	Valid	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		.54	1.28	2.04	2.26	2.58	3.12
Median		.00	1.00	1.00	2.50	2.00	3.50
Mode		0	1	1	3	2	4
Sum		27	64	102	113	129	156
Percentiles	25	.00	1.00	1.00	1.00	2.00	2.00
	50	.00	1.00	1.00	2.50	2.00	3.50
	75	1.00	1.00	3.00	3.00	3.25	4.00

Post_Q4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	35	70.0	70.0	70.0
	1	8	16.0	16.0	86.0
	2	2	4.0	4.0	90.0
	3	5	10.0	10.0	100.0
	Total	50	100.0	100.0	

Post_Q5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	39	78.0	78.0	78.0
	2	8	16.0	16.0	94.0
	3	3	6.0	6.0	100.0
	Total	50	100.0	100.0	

Post_Q7a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flat - Choro	27	54.0	54.0	54.0
	Flat - Prism	2	4.0	4.0	58.0
	Globe - Choro	13	26.0	26.0	84.0
	Globe - Prism	8	16.0	16.0	100.0
	Total	50	100.0	100.0	

Post_Q7b

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flat - Choropleth	17	34.0	34.0	34.0
	Flat - Prism	8	16.0	16.0	50.0
	VG - Choropleth	20	40.0	40.0	90.0
	VG - Prism	5	10.0	10.0	100.0
	Total	50	100.0	100.0	

Post_Q7c

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flat - Choropleth	5	10.0	10.0	10.0
	Flat - Prism	23	46.0	46.0	56.0
	VG - Choropleth	10	20.0	20.0	76.0
	VG - Prism	12	24.0	24.0	100.0
	Total	50	100.0	100.0	

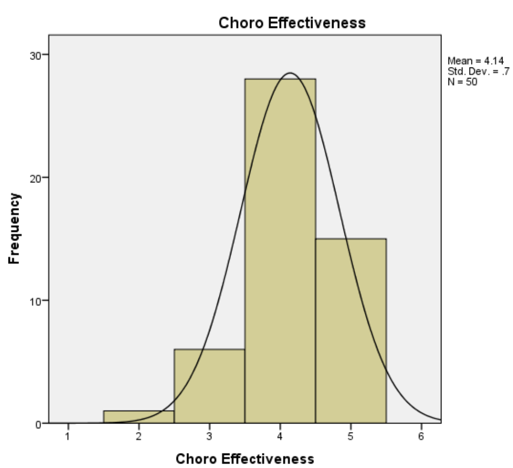
Post_Q7d

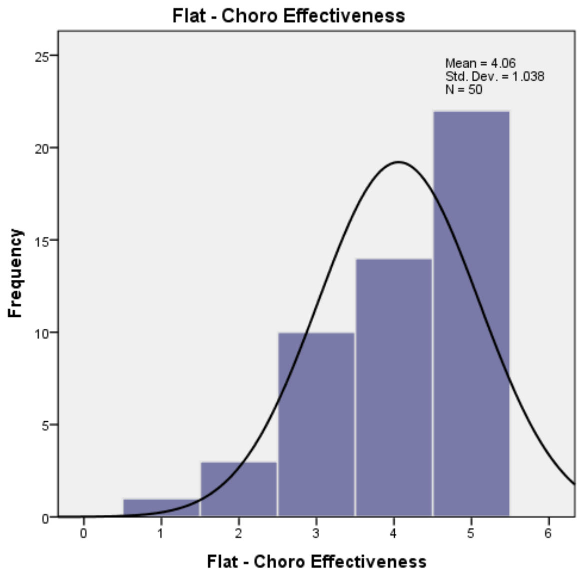
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flat - Choropleth	1	2.0	2.0	2.0
	Flat - Prism	17	34.0	34.0	36.0
	VG - Choropleth	7	14.0	14.0	50.0
	VG - Prism	25	50.0	50.0	100.0
	Total	50	100.0	100.0	

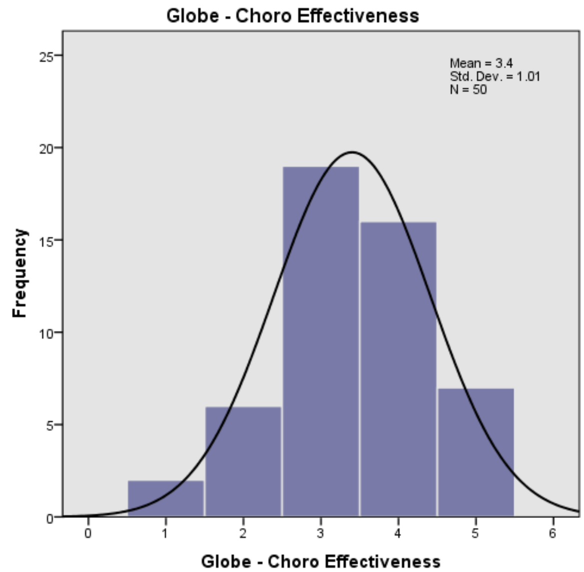
Effectivess Frequencies: Questions 1a, 1b, 2a, 2b, 3a, and 3b

Statistics

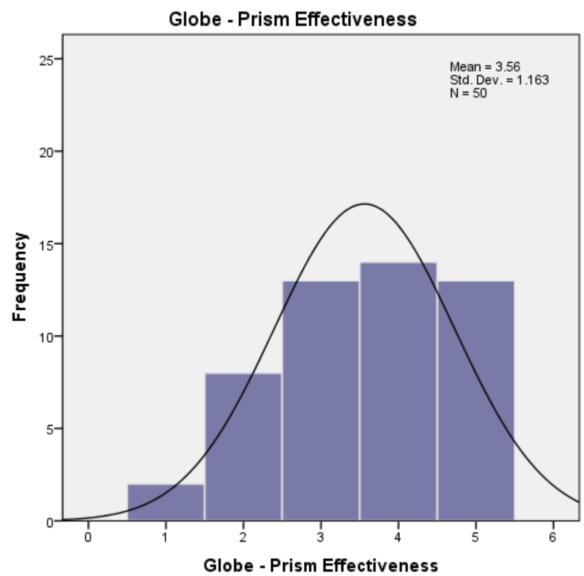
		Choro Effectiveness	Prism Effectiveness	Flat - Choro Effectiveness	Globe - Choro Effectiveness	Flat - Prism Effectiveness	Globe - Prism Effectiveness
N	Valid	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		4.14	2.98	4.06	3.40	3.24	3.56
Median		4.00	3.00	4.00	3.00	3.00	4.00
Std. Deviation		.700	1.059	1.038	1.010	1.135	1.163
Variance		.490	1.122	1.078	1.020	1.288	1.353
Skewness		-.571	.148	-.922	-.272	-.409	-.354
Std. Error of Skewness		.337	.337	.337	.337	.337	.337
Kurtosis		.582	-.636	.212	-.139	-.370	-.788
Std. Error of Kurtosis		.662	.662	.662	.662	.662	.662
Minimum		2	1	1	1	1	1
Maximum		5	5	5	5	5	5
Percentiles	25	4.00	2.00	3.00	3.00	3.00	3.00
	50	4.00	3.00	4.00	3.00	3.00	4.00
	75	5.00	4.00	5.00	4.00	4.00	5.00




Flat - Choro Effectiveness
Mean = 4.06
Std. Dev. = 1.038
N = 50
Frequency
Flat - Choro Effectiveness


Globe - Choro Effectiveness
Mean = 3.4
Std. Dev. = 1.01
N = 50
Frequency
Globe - Choro Effectiveness


Flat - Prism Effectiveness
Mean = 3.24
Std. Dev. = 1.135
N = 50
Frequency
Flat - Prism Effectiveness


Globe - Prism Effectiveness
Mean = 3.56
Std. Dev. = 1.163
N = 50
Frequency
Globe - Prism Effectiveness

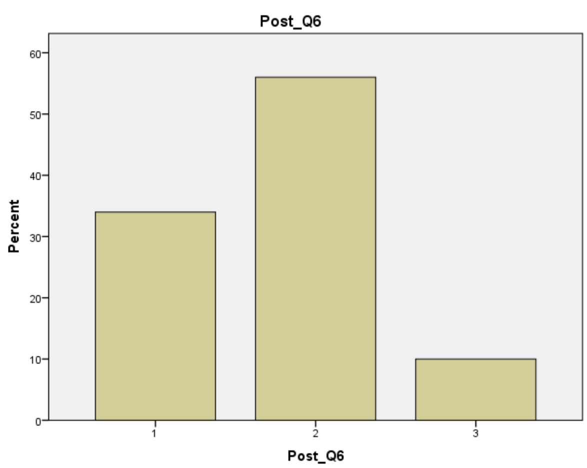
Effectiveness Frequencies: Questions 6 and 9

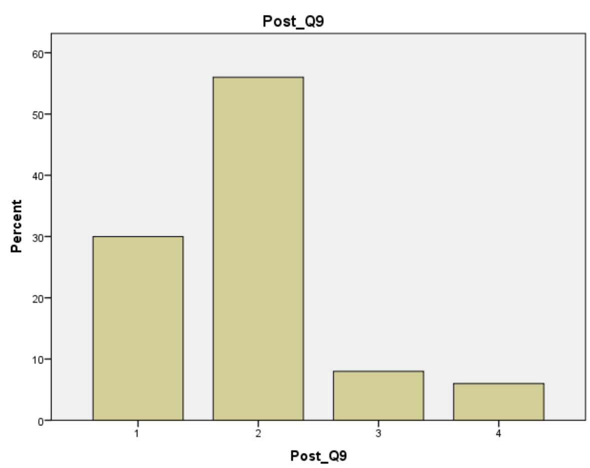
Post_Q6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	17	34.0	34.0	34.0
	2	28	56.0	56.0	90.0
	3	5	10.0	10.0	100.0
	Total	50	100.0	100.0	

Post_Q9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	15	30.0	30.0	30.0
	2	28	56.0	56.0	86.0
	3	4	8.0	8.0	94.0
	4	3	6.0	6.0	100.0
	Total	50	100.0	100.0	

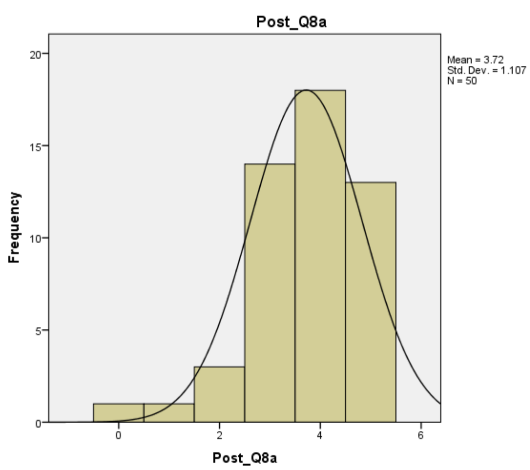


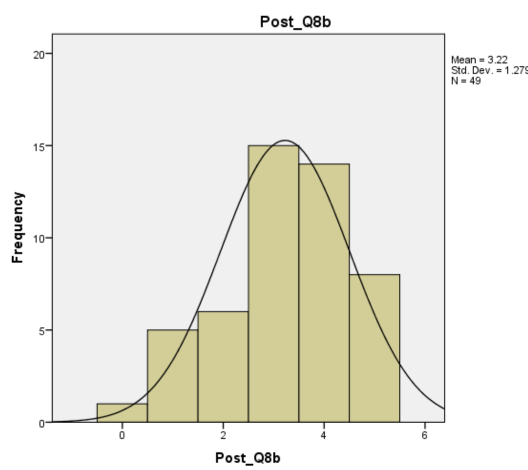


Effectiveness Frequencies: Questions 8a and 8b

Statistics

		Post_Q8a	Post_Q8b
N	Valid	50	49
	Missing	0	1
Mean		3.72	3.22
Median		4.00	3.00
Mode		4	3
Std. Deviation		1.107	1.279
Variance		1.226	1.636
Skewness		-1.009	-.503
Std. Error of Skewness		.337	.340
Kurtosis		1.583	-.298
Std. Error of Kurtosis		.662	.668
Minimum		0	0
Maximum		5	5
Sum		186	158
Percentiles	25	3.00	2.50
	50	4.00	3.00
	75	5.00	4.00





Repeated Measures ANOVA: Map Combination Effectiveness

Descriptive Statistics

	Mean	Std. Deviation	N
Flat - Choro Effectiveness	4.06	1.038	50
Globe - Choro Effectiveness	3.40	1.010	50
Flat - Prism Effectiveness	3.24	1.135	50
Globe - Prism Effectiveness	3.56	1.163	50

Mauchly's Test of Sphericity[a]

Measure: Score

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ComboEffect	.789	11.313	5	.046	.857	.908	.333

Tests of Within-Subjects Effects

Measure: Score

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ComboEffect	Sphericity Assumed	18.895	3	6.298	5.091	.002	.094
	Greenhouse-Geisser	18.895	2.570	7.351	5.091	.004	.094
	Huynh-Feldt	18.895	2.725	6.934	5.091	.003	.094
	Lower-bound	18.895	1.000	18.895	5.091	.029	.094
Error(ComboEffect)	Sphericity Assumed	181.855	147	1.237			
	Greenhouse-Geisser	181.855	125.952	1.444			
	Huynh-Feldt	181.855	133.527	1.362			
	Lower-bound	181.855	49.000	3.711			

Tests of Between-Subjects Effects

Measure: Score

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2541.845	1	2541.845	2470.993	.000	.981
Error	50.405	49	1.029			

Pairwise Comparisons

Measure: Score

(I) ComboEffect	(J) ComboEffect	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.660*	.213	.019	.074	1.246
	3	.820*	.197	.001	.277	1.363
	4	.500	.233	.219	-.139	1.139
2	1	-.660*	.213	.019	-1.246	-.074
	3	.160	.220	1.000	-.445	.765
	4	-.160	.195	1.000	-.695	.375
3	1	-.820*	.197	.001	-1.363	-.277
	2	-.160	.220	1.000	-.765	.445
	4	-.320	.269	1.000	-1.059	.419
4	1	-.500	.233	.219	-1.139	.139
	2	.160	.195	1.000	-.375	.695
	3	.320	.269	1.000	-.419	1.059

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Independent Samples T-Test: Symbolization Preference * Symbolization Accuracy Rate

Group Statistics

	SymbolPref	N	Mean	Std. Deviation	Std. Error Mean
SymbolAccRate	Choropleth maps	40	.73500	.248723	.039327
	Prism maps	10	.40667	.171270	.054160

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SymbolAccRate	Equal variances assumed	.852	.360	3.933	48	.000	.328333	.083489	.160467	.496200
	Equal variances not assumed			4.905	19.727	.000	.328333	.066932	.188591	.468075

Independent Samples T-Test: Map Medium Preference * Medium Accuracy Rate

Group Statistics

	MedPref	N	Mean	Std. Deviation	Std. Error Mean
MediumAccRate	Flat Map	29	.67126	.232605	.043194
	Virtual Globe	21	.58413	.232766	.050794

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
MediumAccRate	Equal variances assumed	.053	.819	1.307	48	.197	.087137	.066668	-.046909	.221183
	Equal variances not assumed			1.307	43.235	.198	.087137	.066676	-.047306	.221581

Map Variable and Map Combination Preferences * Completion Times

Descriptive Statistics

Dependent Variable: TimePref_Combo

Post_Q7a	Mean	Std. Deviation	N
Flat - Choro	210.26	68.580	27
Flat - Prism	299.50	146.371	2
Globe - Choro	228.38	43.210	13
Globe - Prism	383.88	149.796	8
Total	246.32	102.967	50

Levene's Test of Equality of Error Variances[a]

Dependent Variable: TimePref_Combo

F	df1	df2	Sig.
6.500	3	46	.001

Tests of Between-Subjects Effects

Dependent Variable: TimePref_Combo

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	196319.243[a]	3	65439.748	9.314	.000	.378
Intercept	1703645.882	1	1703645.882	242.484	.000	.841
Post_Q7a	196319.243	3	65439.748	9.314	.000	.378
Error	323187.637	46	7025.818			
Total	3553184.000	50				
Corrected Total	519506.880	49				

a. R Squared = .378 (Adjusted R Squared = .337)

Estimates

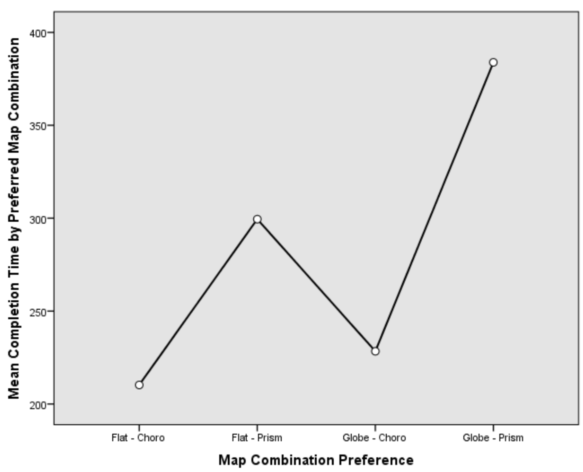
Dependent Variable: TimePref_Combo

Post_Q7a	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Flat - Choro	210.259	16.131	177.789	242.730
Flat - Prism	299.500	59.270	180.196	418.804
Globe - Choro	228.385	23.248	181.590	275.179
Globe - Prism	383.875	29.635	324.223	443.527

Pairwise Comparisons

Dependent Variable: TimePref_Combo

(I) Post_Q7a	(J) Post_Q7a	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Flat - Choro	Flat - Prism	-89.241	61.426	.918	-258.602	80.121
	Globe - Choro	-18.125	28.296	1.000	-96.142	59.892
	Globe - Prism	-173.616*	33.741	.000	-266.645	-80.586
Flat - Prism	Flat - Choro	89.241	61.426	.918	-80.121	258.602
	Globe - Choro	71.115	63.666	1.000	-104.423	246.654
	Globe - Prism	-84.375	66.266	1.000	-267.081	98.331
Globe - Choro	Flat - Choro	18.125	28.296	1.000	-59.892	96.142
	Flat - Prism	-71.115	63.666	1.000	-246.654	104.423
	Globe - Prism	-155.490*	37.665	.001	-259.340	-51.641
Globe - Prism	Flat - Choro	173.616*	33.741	.000	80.586	266.645
	Flat - Prism	84.375	66.266	1.000	-98.331	267.081
	Globe - Choro	155.490*	37.665	.001	51.641	259.340



Independent Samples T-Test: Map Medium Preference * Time

Group Statistics

	MedPref	N	Mean	Std. Deviation	Std. Error Mean
TimePref_Medium	Flat Map	29	245.655	71.8651	13.3450
	Virtual Globe	21	296.952	99.4267	21.6967

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
TimePref_Medium	Equal variances assumed	.786	.380	-2.120	48	.039	-51.2972	24.1976	-99.9498	-2.6446
	Equal variances not assumed			-2.014	34.471	.052	-51.2972	25.4723	-103.0370	.4426

Independent Samples T-Test: Symbolization Preference * Time

Group Statistics

	SymbolPref	N	Mean	Std. Deviation	Std. Error Mean
TimePref_Symbol	Choropleth maps	40	222.813	52.7540	8.3411
	Prism maps	10	352.450	129.4449	40.9341

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
TimePref_Symbol	Equal variances assumed	22.105	.000	-4.988	48	.000	-129.6375	25.9878	-181.8894	-77.3856
	Equal variances not assumed			-3.103	9.759	.012	-129.6375	41.7753	-223.0310	-36.2440

Repeated Measures ANOVA: Map Combination Effectiveness * Map Combo Preference

Descriptive Statistics

	Post_Q7a	Mean	Std. Deviation	N
Flat - Choro Effectiveness	Flat - Choro	4.44	.801	27
	Flat - Prism	3.50	.707	2
	Globe - Choro	3.77	1.092	13
	Globe - Prism	3.38	1.302	8
	Total	4.06	1.038	50
Globe - Choro Effectiveness	Flat - Choro	3.22	1.050	27
	Flat - Prism	3.00	.000	2
	Globe - Choro	3.69	1.032	13
	Globe - Prism	3.63	.916	8
	Total	3.40	1.010	50
Flat - Prism Effectiveness	Flat - Choro	3.67	.920	27
	Flat - Prism	4.50	.707	2
	Globe - Choro	2.62	1.261	13
	Globe - Prism	2.50	.756	8
	Total	3.24	1.135	50
Globe - Prism Effectiveness	Flat - Choro	3.07	1.207	27
	Flat - Prism	3.00	.000	2
	Globe - Choro	4.08	.760	13
	Globe - Prism	4.50	.756	8
	Total	3.56	1.163	50

Mauchly's Test of Sphericity[a]

Measure: Combo

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ComboRating	.953	2.153	5	.828	.970	1.000	.333

Tests of Within-Subjects Effects

Measure: Combo

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ComboRating	Sphericity Assumed	3.055	3	1.018	1.041	.376	.022
ComboRating * Post_Q7a	Sphericity Assumed	46.896	9	5.211	5.328	.000	.258
Error(ComboRating)	Sphericity Assumed	134.959	138	.978			

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Flat - Choro Effectiveness	1.185	3	46	.326
Globe - Choro Effectiveness	1.179	3	46	.328
Flat - Prism Effectiveness	1.357	3	46	.268
Globe - Prism Effectiveness	3.081	3	46	.037

Tests of Between-Subjects Effects

Measure: Combo

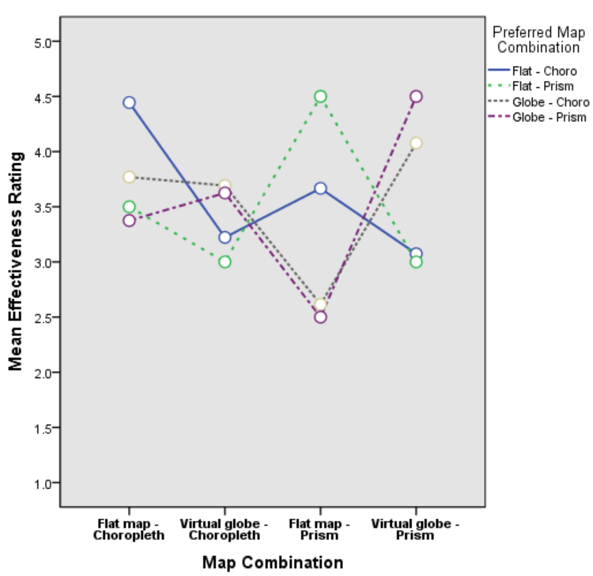
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1082.323	1	1082.323	994.689	.000	.956
Post_Q7a	.352	3	.117	.108	.955	.007
Error	50.053	46	1.088			

4. Post_Q7a * ComboRating

Measure: Combo

Post_Q7a	ComboRating	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Flat - Choro	1	4.444	.187	4.068	4.820
	2	3.222	.195	2.829	3.615
	3	3.667	.192	3.281	4.052
	4	3.074	.198	2.675	3.473
Flat - Prism	1	3.500	.686	2.118	4.882
	2	3.000	.717	1.557	4.443
	3	4.500	.704	3.083	5.917
	4	3.000	.728	1.534	4.466
Globe - Choro	1	3.769	.269	3.227	4.311
	2	3.692	.281	3.126	4.258
	3	2.615	.276	2.060	3.171
	4	4.077	.286	3.502	4.652
Globe - Prism	1	3.375	.343	2.684	4.066
	2	3.625	.359	2.903	4.347
	3	2.500	.352	1.792	3.208
	4	4.500	.364	3.767	5.233



Repeated Measures ANOVA: Map Medium Effectiveness * Map Medium Preference

Descriptive Statistics

	MedPref	Mean	Std. Deviation	N
Flat_Effect	Flat Map	3.79310	.661671	29
	Virtual Globe	3.64286	.744024	21
	Total	3.73000	.694071	50
Globe_Effect	Flat Map	3.39655	.673203	29
	Virtual Globe	3.40476	.624881	21
	Total	3.40000	.646813	50

Mauchly's Test of Sphericity[a]

Measure: Medium

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
MediumEffect	1.000	.000	0	.	1.000	1.000	1.000

Tests of Within-Subjects Effects

Measure: Medium

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MediumEffect	Sphericity Assumed	2.453	1	2.453	6.280	.016	.116
	Greenhouse-Geisser	2.453	1.000	2.453	6.280	.016	.116
	Huynh-Feldt	2.453	1.000	2.453	6.280	.016	.116
	Lower-bound	2.453	1.000	2.453	6.280	.016	.116
MediumEffect * MedPref	Sphericity Assumed	.153	1	.153	.391	.534	.008
	Greenhouse-Geisser	.153	1.000	.153	.391	.534	.008
	Huynh-Feldt	.153	1.000	.153	.391	.534	.008
	Lower-bound	.153	1.000	.153	.391	.534	.008
Error(MediumEffect)	Sphericity Assumed	18.750	48	.391			
	Greenhouse-Geisser	18.750	48.000	.391			
	Huynh-Feldt	18.750	48.000	.391			
	Lower-bound	18.750	48.000	.391			

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Flat_Effect	.238	1	48	.628
Globe_Effect	.115	1	48	.736

Tests of Between-Subjects Effects

Measure: Medium

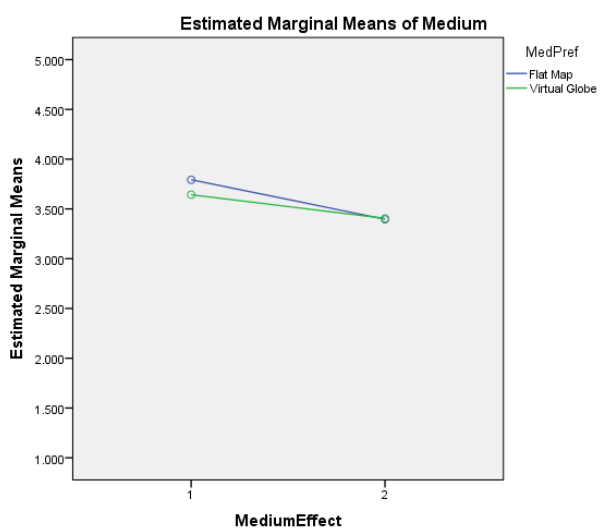
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1234.443	1	1234.443	2362.604	.000	.980
MedPref	.123	1	.123	.235	.630	.005
Error	25.080	48	.522			

4. MedPref * MediumEffect

Measure: Medium

MedPref	MediumEffect	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Flat Map	1	3.793	.129	3.533	4.053
	2	3.397	.121	3.153	3.641
Virtual Globe	1	3.643	.152	3.337	3.949
	2	3.405	.143	3.118	3.691



Repeated Measures ANOVA: Symbolization Effectiveness * Symbol Preference

Descriptive Statistics

	ComboPref_no1	Mean	Std. Deviation	N
Choro Effectiveness	Choropleth maps	4.22	.698	40
	Prism maps	3.80	.632	10
	Total	4.14	.700	50
Prism Effectiveness	Choropleth maps	2.82	.984	40
	Prism maps	3.60	1.174	10
	Total	2.98	1.059	50

Mauchly's Test of Sphericity[a]

Measure: SymbolPref

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
SymbolRating	1.000	.000	0	.	1.000	1.000	1.000

Tests of Within-Subjects Effects

Measure: SymbolPref

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SymbolRating	Sphericity Assumed	10.240	1	10.240	12.734	.001	.210
	Greenhouse-Geisser	10.240	1.000	10.240	12.734	.001	.210
	Huynh-Feldt	10.240	1.000	10.240	12.734	.001	.210
	Lower-bound	10.240	1.000	10.240	12.734	.001	.210
SymbolRating * ComboPref_no1	Sphericity Assumed	5.760	1	5.760	7.163	.010	.130
	Greenhouse-Geisser	5.760	1.000	5.760	7.163	.010	.130
	Huynh-Feldt	5.760	1.000	5.760	7.163	.010	.130
	Lower-bound	5.760	1.000	5.760	7.163	.010	.130
Error(SymbolRating)	Sphericity Assumed	38.600	48	.804			
	Greenhouse-Geisser	38.600	48.000	.804			
	Huynh-Feldt	38.600	48.000	.804			
	Lower-bound	38.600	48.000	.804			

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Choro Effectiveness	.176	1	48	.676
Prism Effectiveness	.142	1	48	.708

Tests of Between-Subjects Effects

Measure: SymbolPref

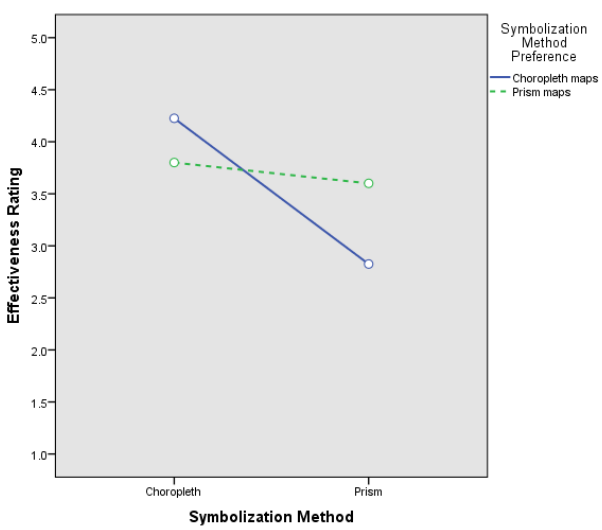
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	835.210	1	835.210	1173.941	.000	.961
ComboPref_no1	.490	1	.490	.689	.411	.014
Error	34.150	48	.711			

4. ComboPref_no1 * SymbolRating

Measure: SymbolPref

ComboPref_no1	SymbolRating	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Choropleth maps	1	4.225	.108	4.007	4.443
	2	2.825	.162	2.500	3.150
Prism maps	1	3.800	.217	3.364	4.236
	2	3.600	.323	2.950	4.250



Independent Samples T-Test: Map Medium Effectiveness * Preference

Group Statistics

	MedPref	N	Mean	Std. Deviation	Std. Error Mean
Flat_Effect	Flat Map	29	3.79310	.661671	.122869
	Virtual Globe	21	3.64286	.744024	.162359
Globe_Effect	Flat Map	29	3.39655	.673203	.125011
	Virtual Globe	21	3.40476	.624881	.136360

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Flat_Effect	Equal variances assumed	.238	.628	.752	48	.456	.150246	.199762	-.251403	.551895
	Equal variances not assumed			.738	40.078	.465	.150246	.203611	-.261241	.561734
Globe_Effect	Equal variances assumed	.115	.736	-.044	48	.965	-.008210	.187251	-.384703	.368283
	Equal variances not assumed			-.044	45.027	.965	-.008210	.184991	-.380795	.364375

Independent Samples T-Test: Symbolization Effectiveness * Preference

Group Statistics

	SymbolPref	N	Mean	Std. Deviation	Std. Error Mean
Choro Effectiveness	Choropleth maps	40	4.23	.698	.110
	Prism maps	10	3.80	.632	.200
Prism Effectiveness	Choropleth maps	40	2.83	.984	.156
	Prism maps	10	3.60	1.174	.371

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Choro Effectiveness	Equal variances assumed	.176	.676	1.753	48	.086	.425	.242	-.063	.913
	Equal variances not assumed			1.861	14.986	.083	.425	.228	-.062	.912
Prism Effectiveness	Equal variances assumed	.142	.708	-2.144	48	.037	-.775	.361	-1.502	-.048
	Equal variances not assumed			-1.926	12.353	.077	-.775	.402	-1.649	.099

APPENDIX I: PARTICIPANT ANSWERS

Part	Time	Sex	Age	Year	Major	Course	Country	State	County	Glasses	Colorblind	Paper_use	Online_use	VG_use	Carto	Experience	Lang_Barrier	Geog_Lit	Carto_Lit	Pre_Q1
1	11:00am	1	20	2	2	1	2	0	0	1	2	2	2	4	2	2	2	2	2	3
2	11:30am	1	20	2	2	1	2	0	0	2	2	3	3	2	2	2	1	3	2	3
3	10:00am	1	22	4	1	3	1	1	1	1	2	2	1	1	1	1	2	2	2	4
4	10:25am	1	21	4	1	3	1	1	2	1	2	2	1	1	1	1	2	2	2	4
5	10:45am	1	22	5	1	3	1	1	3	2	2	3	1	2	1	1	2	2	2	2
6	2:30pm	2	20	1	3	1	3	0	0	1	2	2	1	2	2	2	3	1	2	3
7	9:00am	2	20	2	4	1	1	1	4	2	2	2	2	3	2	2	2	1	2	4
8	12:30pm	1	19	1	5	1	4	0	0	2	2	2	1	3	2	2	1	3	2	2
9	2:00pm	1	23	2	2	1	3	0	0	1	2	2	2	2	2	2	3	2	2	1
10	9:00am	1	24	4	6	1	1	1	3	1	2	3	1	2	2	2	2	2	2	4
11	9:30am	2	20	2	7	1	1	2	0	2	2	3	3	3	2	2	2	1	2	2
12	10:00am	1	18	1	8	1	5	0	0	2	2	2	2	3	2	2	2	2	2	3
13	12:30pm	1	20	2	5	1	1	3	0	2	2	3	2	2	2	2	2	2	2	1
14	8:30am	1	19	1	2	1	1	1	5	2	2	2	1	2	2	2	2	2	1	4
15	6:55pm	1	20	3	1	3	1	1	6	2	2	1	1	2	1	1	2	2	2	2
16	7:24pm	1	23	5	1	3	1	1	2	2	2	2	1	1	1	1	2	2	2	0
17	9:30am	1	20	1	5	1	4	0	0	2	2	3	4	1	2	1	2	2	2	3
18	12:30pm	1	21	2	5	1	4	0	0	2	2	3	3	2	2	2	2	2	2	0
19	1:00pm	2	21	2	9	1	1	1	2	2	2	3	3	2	2	2	2	1	1	4
20	1:30pm	2	21	3	10	1	3	0	0	1	2	2	1	1	2	2	2	2	2	4
21	2:00pm	1	21	3	1	3	1	1	3	2	2	1	1	1	1	1	2	2	2	3
22	2:20pm	2	20	2	3	1	3	0	0	1	2	3	1	3	2	2	1	2	2	2
23	2:40pm	2	21	2	3	1	3	0	0	1	2	3	2	3	2	2	1	3	1	4
24	3:40pm	1	20	1	11	1	6	0	0	1	2	4	3	4	2	2	3	2	2	0
25	8:30am	1	19	1	2	1	1	1	5	2	2	3	3	3	2	2	2	2	1	4
26	10:00am	1	21	1	12	1	7	0	0	2	2	3	2	2	2	2	2	2	1	4
27	11:00am	1	20	2	13	1	1	1	0	1	2	3	2	2	2	2	2	2	2	0
28	11:30am	1	36	4	1	7	1	1	3	1	2	1	2	2	1	1	2	2	2	0
29	12:15pm	1	20	2	5	1	6	0	0	2	2	3	1	1	2	2	2	2	2	2
30	12:35pm	1	23	4	5	1	6	0	0	2	1	4	3	3	1	1	2	2	2	2
31	1:00pm	1	23	2	5	1	6	0	0	2	3	3	3	3	2	2	2	3	1	2
32	1:45pm	1	20	1	5	1	4	0	0	2	2	3	1	3	2	2	2	2	1	0
33	12:30pm	1	26	5	1	5	1	1	7	1	2	1	1	1	1	1	2	2	2	4
34	1:15pm	1	21	4	10	1	1	1	2	1	2	3	2	3	1	2	2	2	1	0
35	1:25pm	1	52	4	1	1	1	1	0	1	2	2	1	2	1	1	2	2	2	2
36	1:45pm	1	25	4	10	1	1	1	3	2	3	2	2	3	1	1	2	2	1	1
37	2:10pm	2	22	4	10	1	1	4	0	1	2	2	2	2	1	2	2	1	2	1
38	2:30pm	2	22	4	10	1	1	3	0	1	2	3	3	3	1	1	2	2	1	1
39	2:45pm	1	24	5	1	5	1	1	8	1	2	1	1	2	1	1	2	2	2	3
40	3:05pm	1	22	4	10	1	1	1	2	1	2	3	2	3	1	1	2	2	1	3
41	8:50am	1	20	2	14	1	1	1	2	2	2	3	2	2	2	1	2	1	1	3
42	10:30am	1	24	6	1	7	1	1	9	2	2	1	1	1	1	1	2	2	2	4
43	11:10am	2	21	3	1	5	1	1	10	2	2	2	2	2	1	1	2	2	2	4
44	12:00pm	1	33	5	1	5	1	1	3	2	2	1	2	2	1	1	2	2	2	1
45	1:20pm	1	27	6	1	7	1	1	7	1	2	1	1	2	2	1	2	2	2	4
46	2:00pm	1	23	5	1	5	1	1	6	1	2	1	2	2	1	1	2	2	2	0
47	2:45pm	1	20	2	1	1	1	1	11	1	2	2	2	1	1	1	2	2	2	4
48	3:05pm	1	19	1	1	1	1	1	2	2	2	2	1	2	1	1	2	2	2	2
49	3:25pm	1	24	6	1	7	1	1	0	1	2	2	1	1	2	1	2	2	2	1
50	8:30am	2	19	2	2	1	1	1	0	2	2	3	2	2	2	2	2	1	1	2
51	10:40am	2	25	5	1	5	1	1	3	2	2	1	1	3	2	1	2	1	2	2
52	12:15pm	1	25	6	1	7	1	1	0	2	2	2	2	3	1	1	2	2	1	1

Part	Pre_Q2	Pre_Q3	Pre_Q4	Pre_Q5a	Pre_Q5b	Pre_Q6	Pre_Q7	Task1.1	Task1.2a	Task1.2b	Task1.3	Task1.4a	Task1.4b	Task2.1	Task2.2a	Task2.2b	Task2.3	Task2.4a	Task2.4b
1	1	1	2	1	3	2	3	2	#NULL!	#NULL!	#NULL!	1	#NULL!	2	#NULL!	#NULL!	1	#NULL!	#NULL!
2	1	2	2	1	3	3	3	2	3	#NULL!	#NULL!	2	#NULL!	2	#NULL!	#NULL!	2	#NULL!	3
3	1	2	2	2	2	1	1	2	3	#NULL!	1	1	-4.5	1	2	-12	1	2	1
4	2	2	2	2	1	1	1	2	1	-2	2	1	20.0	1	2	18	1	2	1
5	1	2	1	2	0	1	1	2	1	2	1	1	-6.0	1	1	-3	2	2	3
6	1	1	1	2	1	3	3	2	3	#NULL!	2	1	6.0	2	2	-32	2	2	2
7	1	2	1	2	2	1	2	1	1	0	1	2	15.0	1	2	-24	2	1	3
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21	1	2	2	1	4	1	1	2	1	0	2	1	1.0	1	3	#NULL!	1	2	1
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41	2	2	1	4	1	1	2	1	1	-4	1	1	16.0	1	3	#NULL!	1	2	3
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43	1	1	3	1	4	1	2	2	1	9	1	1	11.0	1	1	5	1	1	3
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45	1	1	3	2	2	1	1	1	3	#NULL!	1	1	11.0	1	1	-3	2	1	1
46	1	2	2	2	2	1	1	2	2	-12	1	2	0.0	1	2	13	1	2	3
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48	1	2	2	2	2	1	2	1	1	-9	1	1	5.0	1	1	-6	1	1	1
49	1	1	3	2	0	1	1	1	1	0	1	1	4.0	1	1	-3	2	2	3
50	1	2	3	3	0	2	2	2	1	6	2	2	45.0	1	2	-14	1	2	1
51	1	2	2	2	1	2	2	2	3	#NULL!	2	1	16.0	1	2	13	1	2	1
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Part	Task3.1	Task3.2a	Task3.2b	Task3.3	Task3.4a	Task3.4b	Task4.1	Task4.2	Task4.3	Task4.4a	Task4.4b	Post_Q1a	Post_Q1b	Post_Q2a	Post_Q2b	Post_Q3a	Post_Q3b	Post_Q4
1	2	#NULL!	#NULL!	#NULL!	2	#NULL!	#NULL!	#NULL!	#NULL!	2	#NULL!	4	2	4	4	3	3	0
2	2	3	#NULL!	#NULL!	3	#NULL!	1	1	-1	2	3	2	2	5	5	4	4	0
3	2	3	#NULL!	12	2	2	1	1	17	3	2	5	3	5	3	2	5	0
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5	2	2	-15	7	3	1	1	2	2	2	1	4	3	5	3	4	3	0
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12	1	3	#NULL!	-5	3	1	1	2	2	2	1	5	2	5	1	5	4	0
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17	2	2	43	-8	2	1	1	1	17	2	3	5	3	5	4	5	4	0
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21	1	3	#NULL!	-37	1	1	1	1	-3	1	3	4	2	5	3	4	2	0
22	1	3	#NULL!	-7	3	1	2	2	3	2	1	4	5	4	3	4	5	3
23	2	2	73	-8	2	1	1	1	8	2	1	3	4	3	3	2	4	0
24	2	1	21	-13	2	2	1	1	-17	2	2	3	1	1	4	1	3	0
25	1	2	25	1	2	1	1	1	7	2	2	2	4	4	2	4	3	0
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27	2	1	3	18	2	1	1	1	7	3	1	4	1	4	2	4	2	0
28	2	1	3	-8	1	2	1	1	22	3	1	4	4	5	4	1	5	0
29	1	2	-31	-29	1	1	1	1	-3	3	2	5	3	4	3	1	4	0
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31	1	2	-25	-4	2	1	1	2	7	2	2	3	5	3	2	2	4	0
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33	2	2	41	17	2	1	1	1	-3	2	3	4	3	3	5	5	4	0
34	1	1	2	-1	2	2	2	1	-1	3	2	4	2	5	5	3	5	0
35	1	1	-5	1	1	1	1	1	2	3	3	4	3	5	4	5	4	0
36	2	1	-10	7	1	1	1	1	4	2	1	4	2	4	4	4	2	0
37	1	1	2	11	3	1	2	2	-1	2	3	4	1	5	3	3	1	0
38	2	1	-1	-17	2	1	1	1	7	3	2	4	4	4	4	3	3	0
39	1	2	34	-8	2	1	1	2	14	3	2	4	2	5	4	3	4	0
40	2	2	46	-48	3	1	1	1	-18	2	1	4	2	3	4	2	4	0
41	1	2	15	-28	3	1	2	1	17	3	2	4	3	3	3	5	3	0
42	1	1	-5	-4	3	2	1	1	3	3	3	5	2	4	2	3	2	1
43	1	1	-3	-8	1	1	1	1	-3	2	2	5	4	5	3	3	4	3
44	2	1	0	-5	1	1	1	1	-8	2	1	5	2	5	1	1	5	1
45	1	2	15	-3	2	1	1	1	2	2	1	4	4	5	4	2	5	2
46	1	3	#NULL!	-8	2	1	1	1	2	2	2	4	3	4	3	3	3	2
47	1	1	3	-3	1	1	1	2	-1	1	1	4	2	5	4	4	2	1
48	1	2	15	-14	1	1	1	1	27	2	1	4	3	5	4	4	2	1
49	1	1	-9	-4	3	2	1	1	3	2	1	4	2	5	3	4	2	1
50	2	2	20	-8	2	1	1	1	-33	2	2	5	2	5	5	4	2	1
51	2	1	-9	-4	2	1	1	1	-33	2	2	5	3	5	5	2	5	1
52	1	1	2	2	1	1	1	1	0	2	1	4	3	4	3	3	3	1

Part	Post_Q5	Post_Q6	Post_Q7a	Post_Q7b	Post_Q7c	Post_Q7d	Post_Q8a	Post_Q8b	Post_Q9	M1_D	M1_M	M1_S	M1_Ex1	M1_T1	M1_T2	M1_T3	M1_Ex2	M1_T4	M1_Tot	M1_Exp
1	1	3	1	3	4	2	2	2	2	#NULL!	1	2	0	61	50	70	34	31	246	34
2	1	2	1	3	2	4	5	2	2	#NULL!	1	1	0	80	45	17	0	60	202	0
3	1	2	1	3	2	4	5	3	2	1	1	1	0	85	94	25	51	47	302	51
4	2	1	4	2	1	3	5	5	2	4	2	2	81	39	53	35	47	45	300	128
5	1	2	1	3	2	4	3	3	2	2	1	2	0	62	52	31	33	39	217	33
6	1	1	1	3	2	4	3	2	2	1	2	1	0	38	72	35	40	34	219	40
7	1	2	1	3	2	4	4	3	2	2	1	1	26	72	75	89	43	56	361	69
8	1	2	3	1	4	2	2	2	1	3	1	1	0	60	35	35	84	50	264	84
9	2	1	2	1	3	4	5	4	4	1	1	2	0	132	95	61	63	52	403	63
10	1	1	1	4	2	3	4	3	1	2	1	1	28	71	67	28	41	45	280	69
11	1	2	1	2	3	4	5	4	2	3	1	2	0	57	119	65	42	29	312	42
12	1	3	1	2	3	4	3	5	2	1	2	2	0	172	153	116	50	58	549	50
13	2	1	4	3	1	2	4	5	1	1	2	1	0	55	44	27	43	38	207	43
14	1	2	3	1	4	2	4	3	1	3	2	1	0	105	23	22	71	28	249	71
15	1	2	4	1	2	3	4	4	1	2	1	1	0	35	60	45	38	65	243	38
16	2	1	4	3	2	1	0	0	3	2	1	1	0	39	53	22	54	42	210	54
17	1	2	3	1	2	4	5	4	3	2	2	1	0	47	61	47	46	76	277	46
18	1	3	3	1	2	4	4	4	2	3	1	1	17	50	93	23	45	64	292	62
19	1	1	3	1	2	4	4	3	2	1	1	2	0	123	66	94	70	28	381	70
20	1	2	3	1	4	2	5	4	1	2	2	1	0	40	47	27	60	37	211	60
21	1	3	1	3	2	4	3	2	2	4	2	2	0	40	35	25	38	32	170	38
22	2	1	1	4	3	2	5	4	3	2	2	1	0	36	34	42	40	36	188	40
23	1	1	4	1	3	2	4	3	1	3	1	1	0	101	137	141	119	75	573	119
24	1	2	4	1	3	2	3	1	2	1	1	2	0	83	73	32	31	58	277	31
25	1	2	1	3	2	4	4	3	2	1	2	2	16	57	77	47	47	30	274	63
26	1	1	4	1	2	3	3	5	1	2	1	1	26	35	47	47	44	51	250	70
27	3	2	1	2	3	4	4	1	2	4	2	1	49	49	63	67	66	41	335	115
28	2	1	3	2	1	4	4	4	1	2	1	1	37	33	43	30	25	27	195	62
29	1	2	3	1	4	2	5	3	1	1	2	2	0	27	46	50	47	32	202	47
30	1	2	1	3	2	4	5	3	2	3	1	2	88	101	279	80	68	33	649	156
31	1	1	3	1	4	2	5	3	4	2	1	1	0	47	33	65	0	75	220	0
32	1	2	3	1	4	2	4	2	1	2	1	1	0	60	44	43	40	86	273	40
33	1	3	1	3	4	2	5	4	1	1	2	1	46	63	47	42	59	42	299	105
34	1	2	1	3	2	4	4	4	2	3	1	2	0	39	57	39	38	8	181	38
35	3	1	1	2	4	3	3	3	2	3	1	2	0	94	128	37	38	51	348	38
36	1	1	1	2	3	4	5	2	2	2	1	1	0	65	51	33	35	41	225	35
37	1	2	1	3	2	4	3	2	2	2	1	1	0	53	#NULL!	28	46	38	165	46
38	1	2	1	3	2	4	4	#NULL!	2	4	2	2	0	119	63	35	39	19	275	39
39	1	2	1	3	4	2	3	5	3	3	1	2	48	22	56	48	38	35	247	86
40	1	2	3	1	4	2	4	3	1	1	2	1	0	61	34	33	31	31	190	31
41	2	3	2	4	1	3	2	4	2	2	1	1	0	53	27	30	31	44	185	31
42	1	2	1	2	3	4	1	1	2	3	2	1	31	29	30	111	58	46	305	89
43	1	1	1	3	4	2	3	4	2	1	2	2	37	67	56	46	63	57	326	100
44	1	2	1	4	2	3	2	5	2	4	1	2	20	78	131	91	102	62	484	122
45	2	1	4	1	3	2	4	5	1	1	1	1	38	36	127	128	93	55	477	131
46	3	2	3	4	1	2	3	4	4	3	2	2	54	49	68	47	35	73	326	89
47	1	1	1	3	2	4	3	1	2	2	1	2	0	34	53	33	39	38	197	39
48	1	2	1	3	2	4	4	3	2	1	1	1	29	20	55	42	37	18	201	66
49	1	2	1	3	2	4	3	1	2	4	2	1	20	33	28	30	38	25	174	58
50	1	2	1	3	2	4	4	3	2	2	1	2	5	83	73	57	49	37	304	54
51	1	2	3	1	4	2	5	5	1	4	2	2	16	89	131	116	33	78	463	49
52	1	2	1	3	2	4	3	4	2	3	1	1	57	42	98	30	55	53	335	112

Part	M2_D	M2_M	M2_S	M2_Ex1	M2_T1	M2_T2	M2_T3	M2_Ex2	M2_T4	M2_Tot	M2_Exp	M3_D	M3_M	M3_S	M3_Ex1	M3_T1	M3_T2	M3_T3	M3_Ex2	M3_T4	M3_Tot	M3_Exp
1	#NULL!	2	2	26	30	72	32	36	22	218	62	#NULL!	2	1	30	22	98	23	27	11	211	57
2	#NULL!	2	2	0	53	61	29	11	35	189	11	#NULL!	2	1	0	70	56	26	0	23	175	0
3	4	2	2	0	39	31	20	39	29	158	39	3	2	1	0	42	48	43	27	33	193	27
4	2	1	2	77	19	23	41	45	32	237	122	1	1	1	44	20	15	31	23	19	152	67
5	3	2	1	32	50	34	54	34	31	235	66	4	2	2	0	57	34	39	36	27	193	36
6	3	2	2	33	32	34	24	18	21	162	51	2	1	1	34	17	29	39	0	38	157	34
7	4	1	2	48	11	98	41	20	29	247	68	3	2	1	43	52	77	55	27	44	298	70
8	2	2	2	64	74	61	47	67	20	333	131	4	2	1	0	47	58	58	32	26	221	32
9	4	2	1	0	109	39	37	60	28	273	60	2	2	2	0	108	60	56	60	42	326	60
10	4	2	1	0	45	49	37	45	40	216	45	2	1	2	0	82	81	59	34	31	287	34
11	2	1	1	34	57	109	39	30	21	290	64	1	2	2	0	73	97	61	21	23	275	21
12	3	1	1	45	20	56	33	67	56	277	112	4	2	1	0	98	77	80	33	55	343	33
13	2	1	2	19	76	37	41	25	28	226	44	4	2	2	28	15	78	45	19	23	208	47
14	2	1	2	30	56	33	16	54	24	213	84	1	1	1	0	56	52	38	29	18	193	29
15	1	2	1	66	33	84	41	62	54	340	128	4	2	2	74	80	77	60	82	46	419	156
16	4	2	2	46	31	43	43	48	36	247	94	3	1	2	0	103	53	55	53	31	295	53
17	1	1	2	0	79	47	40	40	38	244	40	4	2	2	42	61	69	61	39	25	297	81
18	4	2	2	49	37	117	41	44	38	326	93	2	2	1	0	50	48	51	26	34	209	26
19	3	1	1	57	36	97	32	55	35	312	112	2	2	1	56	24	89	40	37	25	271	93
20	3	1	1	53	18	44	11	10	40	176	63	1	1	2	0	102	48	40	33	50	273	33
21	1	1	2	30	17	44	38	24	37	190	54	3	1	1	0	52	31	27	23	29	162	23
22	4	2	2	39	41	65	51	63	27	286	102	3	1	1	41	39	74	34	51	33	272	92
23	2	2	1	58	41	94	100	107	90	490	165	1	2	2	115	199	51	119	54	47	585	169
24	2	2	1	90	26	36	48	74	45	319	164	1	2	2	0	99	74	83	40	27	323	40
25	2	1	1	51	12	18	25	12	20	138	63	4	2	1	36	37	49	30	29	57	238	65
26	3	1	2	43	26	64	57	47	42	279	90	4	2	1	76	16	38	30	27	29	216	103
27	3	1	2	0	72	87	59	28	51	297	28	1	2	2	87	38	64	71	43	36	339	130
28	4	2	1	37	20	28	33	34	27	179	71	1	2	2	0	108	59	67	29	26	289	29
29	4	2	1	35	26	29	14	34	53	191	69	3	1	2	0	94	48	63	37	26	268	37
30	2	1	1	24	35	21	26	26	18	150	50	1	2	2	0	104	116	69	47	15	351	47
31	1	2	2	0	115	67	30	33	34	279	33	4	2	1	0	25	53	45	28	14	165	28
32	3	1	2	0	69	69	19	41	12	210	41	1	2	2	57	28	62	87	40	48	322	97
33	4	2	2	50	47	40	35	52	26	250	102	3	1	2	37	109	36	85	33	30	330	70
34	2	1	1	0	43	17	12	7	15	94	7	1	2	1	0	35	22	17	16	13	103	16
35	4	2	2	85	27	55	54	37	34	292	122	2	1	1	50	51	22	46	22	18	209	72
36	1	2	1	0	57	44	31	45	20	197	45	3	1	2	0	104	91	36	49	34	314	49
37	3	1	2	0	69	31	34	17	30	181	17	1	2	1	0	63	30	25	25	25	168	25
38	1	2	1	39	35	38	22	17	23	174	56	3	1	2	0	54	41	32	15	13	155	15
39	1	2	1	50	24	63	47	27	21	232	77	4	2	2	60	35	39	39	37	16	226	97
40	2	1	1	28	30	23	25	18	36	160	46	4	2	2	18	27	37	37	17	27	163	35
41	1	2	2	48	32	42	30	27	25	204	75	4	1	2	16	41	33	51	35	20	196	51
42	4	1	2	39	17	28	38	25	62	209	64	2	1	1	37	10	27	26	26	30	156	63
43	2	1	1	19	23	24	37	40	43	186	59	4	1	2	49	44	68	72	54	87	374	103
44	3	2	1	97	30	26	48	69	58	328	166	1	2	2	82	115	133	128	29	19	506	111
45	3	2	2	56	33	144	221	83	81	618	139	4	2	1	38	59	141	83	76	44	441	114
46	1	1	1	70	14	19	27	26	44	200	96	4	2	1	41	33	63	67	47	42	293	88
47	3	2	2	37	38	72	65	33	43	288	70	1	1	1	0	46	26	63	42	32	209	42
48	2	1	2	31	17	46	63	15	27	199	46	4	2	1	25	24	31	24	35	20	159	60
49	3	2	2	54	22	30	58	39	36	239	93	2	1	2	55	24	25	48	36	30	218	91
50	1	2	1	0	52	28	27	24	22	153	24	4	2	2	25	51	50	33	31	22	212	56
51	1	2	1	34	32	70	85	35	32	288	69	2	1	2	63	37	118	134	71	37	460	134
52	2	1	2	83	25	67	73	47	46	341	130	1	2	1	105	12	28	38	46	34	263	151

Part	M4_D	M4_M	M4_S	M4_Ex1	M4_T1	M4_T2	M4_T3	M4_Ex2	M4_T4	M4_Tot	M4_Exp	Time_Total	Explore_Total
1	#NULL!	1	1	0	59	29	30	0	23	141	0	816	153
2	#NULL!	1	2	0	89	18	17	0	20	144	0	710	11
3	2	1	2	79	22	35	30	30	34	230	109	883	226
4	3	2	1	45	32	52	27	26	32	214	71	903	388
5	1	1	1	38	34	27	23	26	28	176	64	821	199
6	4	1	2	0	44	31	17	0	37	129	0	667	125
7	1	2	2	0	397	99	30	36	36	598	36	1,504	243
8	1	1	2	0	157	79	54	42	29	361	42	1,179	289
9	3	1	1	0	85	34	53	38	32	242	38	1,244	221
10	4	2	2	47	57	53	47	43	48	295	90	1,078	238
11	4	2	1	0	95	50	53	47	26	271	47	1,148	174
12	2	1	2	0	154	73	71	72	19	389	72	1,558	267
13	3	1	1	0	44	69	23	23	15	174	23	815	157
14	4	2	2	45	60	83	32	25	13	258	70	913	254
15	3	1	2	64	250	78	75	83	40	590	147	1,592	469
16	2	2	1	30	37	39	41	61	48	256	91	1,008	292
17	3	1	1	35	57	55	42	59	31	279	94	1,097	261
18	1	1	2	24	112	73	60	14	29	312	38	1,139	219
19	4	2	2	74	212	75	60	71	35	527	145	1,491	420
20	4	2	2	0	73	21	16	25	29	164	25	824	181
21	2	2	1	33	44	16	19	23	26	161	56	683	171
22	1	1	2	0	127	58	31	44	23	283	44	1,029	278
23	1	1	2	0	188	80	37	70	78	453	70	2,101	523
24	3	1	1	93	46	38	36	23	31	267	116	1,186	351
25	3	1	2	28	79	38	43	24	21	233	52	883	243
26	1	2	2	106	87	50	44	53	31	371	159	1,116	422
27	2	1	1	0	62	30	31	43	32	198	43	1,169	316
28	3	1	2	38	73	48	30	36	23	248	74	911	236
29	2	1	1	0	52	22	17	23	40	154	23	815	176
30	4	2	1	0	85	28	25	30	16	184	30	1,334	283
31	3	1	2	43	284	120	31	13	16	507	56	1,171	117
32	4	2	1	0	84	52	26	38	25	225	38	1,030	216
33	2	1	1	0	84	51	31	40	24	230	40	1,109	317
34	4	2	2	0	78	20	26	7	12	143	7	521	68
35	1	2	1	0	125	46	37	48	36	292	48	1,141	280
36	4	2	2	34	166	40	35	28	22	325	62	1,061	191
37	4	2	2	11	57	32	22	22	37	181	33	695	121
38	2	1	1	0	47	16	30	12	23	128	12	732	122
39	2	1	1	0	55	24	33	37	37	186	37	891	297
40	3	1	2	0	46	16	21	15	18	116	15	629	127
41	3	2	1	33	64	16	17	18	13	161	51	746	208
42	1	2	2	42	74	39	19	67	40	281	109	951	325
43	3	2	1	23	51	57	47	55	32	265	78	1,151	340
44	2	1	1	33	69	58	64	39	26	289	72	1,607	471
45	2	1	2	46	97	97	116	67	69	492	113	2,028	497
46	2	1	2	34	58	38	35	53	32	250	87	1,069	360
47	4	2	1	28	23	29	35	48	17	180	76	874	227
48	3	2	2	42	57	35	46	36	19	235	78	794	250
49	1	1	1	25	29	15	27	20	23	139	45	770	287
50	3	1	1	21	43	38	12	31	17	162	52	831	186
51	3	1	2	0	87	78	19	37	32	253	37	1,464	289
52	4	2	2	103	44	46	41	45	26	305	148	1,244	541

APPENDIX J: EXPERIMENT DATASETS

CNTRY_NAME	Data_1	Data_2	Data_3	Data_4
Afghanistan	1	89	20	54
Albania	33	18	45	15
Algeria	1	39	31	32
American Samoa	25	61	20	20
Andorra	24	73	89	10
Angola	89	46	47	59
Anguilla	66	84	2	35
Antigua and Barbuda	27	74	30	9
Argentina	17	25	49	72
Armenia	38	4	26	4
Aruba	44	37	48	16
Australia	85	2	1	87
Austria	52	59	75	13
Azerbaijan	47	75	34	2
Bahamas	48	32	20	16
Bahrain	26	50	3	73
Baker I.	53	55	22	32
Bangladesh	29	9	42	52
Barbados	12	48	20	1
Belarus	49	67	64	21
Belgium	30	66	84	73
Belize	21	40	50	6
Benin	29	73	71	6
Bermuda	14	41	6	7
Bhutan	6	18	46	47
Bolivia	27	9	35	72
Bosnia and Herzegovina	34	11	12	48
Botswana	28	13	9	17
Bouvet I.	4	53	25	30
Brazil	12	7	88	7
British Indian Ocean Territory	50	54	24	8
British Virgin Islands	2	28	12	10
Brunei	14	11	6	41
Bulgaria	66	90	81	10
Burkina Faso	88	90	74	67
Burundi	25	41	73	20
Cambodia	69	52	50	63
Cameroon	53	10	67	46
Canada	9	33	36	31
Cape Verde	29	46	39	19
Cayman Islands	3	62	11	29
Central African Republic	81	13	54	45
Chad	41	31	51	34
Chile	38	81	79	47
China	3	13	6	1
Christmas Island	7	76	30	39
Cocos Islands	32	90	5	12
Colombia	8	20	46	81
Comoros	13	31	11	3
Congo	62	6	33	26
Cook Islands	5	58	3	18
Costa Rica	64	1	87	57
Cote d'Ivoire	33	6	14	37
Croatia	70	15	56	29

CNTRY_NAME	Data_1	Data_2	Data_3	Data_4
Cuba	26	42	25	73
Cyprus	2	23	6	44
Czech Republic	84	19	48	75
Democratic Republic of the Congo	20	72	39	88
Denmark	87	46	31	14
Djibouti	15	19	2	87
Dominica	43	35	4	9
Dominican Republic	55	14	32	70
Ecuador	28	85	37	69
Egypt	1	75	41	73
El Salvador	71	20	89	13
Equatorial Guinea	18	16	28	28
Eritrea	31	8	38	42
Estonia	23	3	38	43
Ethiopia	15	83	53	30
Falkland Islands	6	32	8	31
Faroe Islands	30	40	8	16
Fiji	30	43	20	27
Finland	45	12	58	31
France	24	70	54	40
French Guiana	9	30	25	14
French Polynesia	7	1	9	37
French Southern & Antarctic Lands	26	63	3	14
Gabon	37	47	42	29
Gambia	1	17	44	10
Gaza Strip	60	19	61	35
Georgia	57	20	16	12
Germany	5	82	48	53
Ghana	74	27	8	44
Gibraltar	59	65	9	49
Glorioso Islands	52	71	13	45
Greece	48	58	78	75
Greenland	70	72	19	5
Grenada	56	42	26	7
Guadeloupe	42	45	5	15
Guam	35	89	11	12
Guatemala	73	45	86	70
Guernsey	45	68	9	17
Guinea	83	18	43	59
Guinea-Bissau	36	10	1	18
Guyana	9	41	10	88
Haiti	54	1	33	90
Heard I. & McDonald Is.	68	36	20	44
Honduras	40	81	100	3
Howland Island	58	85	12	38
Hungary	75	7	68	27
Iceland	25	34	9	31
India	23	19	29	20
Indonesia	30	4	22	9
Iran	16	74	35	38
Iraq	67	30	4	58
Ireland	59	4	26	25
Isle of Man	34	88	15	50
Israel	58	72	70	12

CNTRY_NAME	Data_1	Data_2	Data_3	Data_4
Italy	22	78	34	35
Jamaica	34	19	47	14
Jan Mayen	55	26	23	22
Japan	17	89	43	39
Jarvis Island	11	64	6	6
Jersey	33	79	27	3
Johnston Atoll	13	25	21	1
Jordan	37	7	52	17
Juan De Nova Island	22	33	11	15
Kazakhstan	77	88	63	27
Kenya	18	52	37	62
Kiribati	17	87	30	11
Kuwait	19	5	18	20
Kyrgyzstan	82	10	62	19
Laos	63	2	85	4
Latvia	8	6	48	19
Lebanon	74	5	34	34
Lesotho	27	1	40	8
Liberia	80	2	36	40
Libya	50	25	30	16
Liechtenstein	61	49	5	47
Lithuania	3	16	30	89
Luxembourg	11	25	23	43
Macedonia	31	2	8	16
Madagascar	73	3	13	83
Malawi	67	30	53	57
Malaysia	30	43	2	42
Maldives	24	12	10	22
Mali	72	89	82	64
Malta	41	29	7	50
Marshall Islands	16	82	7	27
Martinique	5	35	11	18
Mauritania	44	9	24	30
Mauritius	12	7	21	81
Mayotte	38	30	29	3
Mexico	13	79	55	33
Micronesia	48	48	12	19
Midway Islands	51	34	16	23
Moldova	16	8	32	17
Monaco	15	66	18	48
Mongolia	47	3	22	11
Montenegro	10	22	17	7
Montserrat	41	77	2	26
Morocco	13	28	12	90
Mozambique	84	25	18	71
Myanmar	4	86	40	68
Namibia	49	11	19	7
Nauru	46	38	19	28
Nepal	47	73	11	55
Netherlands	43	70	69	50
Netherlands Antilles	57	69	45	8
New Caledonia	36	26	38	18
New Zealand	53	14	83	32
Nicaragua	56	3	29	18

CNTRY_NAME	Data_1	Data_2	Data_3	Data_4
Niger	40	72	80	78
Nigeria	11	5	59	25
Niue	67	56	17	42
Norfolk Island	60	60	14	11
North Korea	25	21	5	66
Northern Mariana Islands	54	39	14	25
Norway	43	9	40	100
Oman	35	7	4	6
Pakistan	19	16	32	74
Palau	49	80	13	13
Panama	50	15	31	30
Papua New Guinea	38	38	72	3
Paraguay	86	6	45	1
Peru	79	53	16	41
Philippines	28	88	33	85
Pitcairn	1	46	15	2
Poland	14	84	45	80
Portugal	46	38	76	41
Puerto Rico	68	7	15	1
Qatar	4	12	37	52
Reunion	32	15	13	74
Romania	28	20	9	86
Russia	25	15	52	84
Rwanda	35	17	55	81
Saint Helena	18	59	18	19
Saint Kitts and Nevis	29	50	16	43
Saint Lucia	69	52	32	13
Saint Pierre and Miquelon	42	31	26	37
Saint Vincent and the Grenadines	21	81	1	15
Samoa	40	78	35	5
San Marino	39	47	10	34
Sao Tome and Principe	28	29	34	2
Saudi Arabia	7	40	10	29
Senegal	65	29	46	44
Serbia	90	13	39	38
Seychelles	47	27	69	20
Sierra Leone	85	13	28	15
Singapore	44	16	36	54
Slovakia	78	10	42	62
Slovenia	22	14	14	5
Solomon Islands	46	6	43	49
Somalia	33	47	60	25
South Africa	26	87	51	75
South Georgia & the South Sandwich Is.	37	86	10	41
South Korea	18	1	30	48
Spain	21	9	58	76
Sri Lanka	30	13	7	36
Sudan	5	74	50	45
Suriname	45	38	35	23
Svalbard	31	70	4	33
Swaziland	17	49	25	37
Sweden	36	79	44	7
Switzerland	79	70	59	46
Syria	39	7	17	61

CNTRY_NAME	Data_1	Data_2	Data_3	Data_4
Tajikistan	88	27	90	8
Tanzania	19	100	56	65
Thailand	14	84	44	43
Timor-Leste	43	4	7	42
Togo	51	21	88	9
Tokelau	64	45	7	24
Tonga	62	44	17	6
Trinidad and Tobago	40	28	27	48
Tunisia	76	5	49	41
Turkey	10	73	57	89
Turkmenistan	32	3	66	58
Turks and Caicos Islands	20	67	17	46
Tuvalu	10	75	29	21
Uganda	7	85	15	77
Ukraine	27	30	38	49
United Arab Emirates	89	17	77	56
United Kingdom	6	90	47	26
United States	7	20	3	30
Uruguay	20	20	50	69
Uzbekistan	100	88	3	51
Vanuatu	63	17	46	17
Vatican City	19	83	1	4
Venezuela	20	38	6	60
Vietnam	9	71	60	28
Virgin Islands	65	43	40	4
Wake Island	8	51	28	36
Wallis and Futuna	23	57	1	40
West Bank	39	18	57	11
Western Sahara	39	37	41	4
Yemen	52	38	19	79
Zambia	61	28	27	60
Zimbabwe	42	62	65	71